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An Acoustical Theory of Vowel Production and Some of its Implications

KENNETH N. STEVENS

ARTHUR S. HOUSE

It is 20 years since the publication of the monograph on the vowel by Chiba and Kajiyama (*3*)—a work that introduces and epitomizes the modern era in the study of speech production and perception. The past two decades have seen a continuous advance in the understanding of the mechanism of speech sound generation, as exemplified by the publication of Fant's treatise (*10*). The fruits of the experimental and theoretical progress, however, have not been universally appreciated and applied. The time may be ripe, therefore, for a concise yet rigorous exposition of current concepts of speech production. The remarks that follow represent an attempt to provide such an exposition on an acoustical theory of vowel production, and to point out its relevance to and compatibility with certain known characteristics of speech.

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Theory of Vowel Production

Vowel sounds are produced by acoustic excitation of the vocal tract by a source at the glottis. The vocal tract is viewed as an acoustic circuit, and the acoustic disturbances in this circuit are usually described in terms of sound pressures and volume velocities of vibration of the air at various points in the circuit. In all cases of present interest, the cross-sectional dimensions of the vocal tract may be considered to be small compared with a wavelength. This means that only plane acoustic waves propagate in the vocal tract, and that the sound pressure and volume velocity measured in the vocal tract are functions of only one spatial dimension—the distance measured along the vocal tract from the glottis.

For those who prefer to think in terms of electric rather than acoustic circuits, the following analogous quantities should be noted: sound pressure p is analogous to voltage; volume velocity U is analogous to current. Acoustic impedance is defined by $Z = p/U$, where p and U are complex amplitudes,

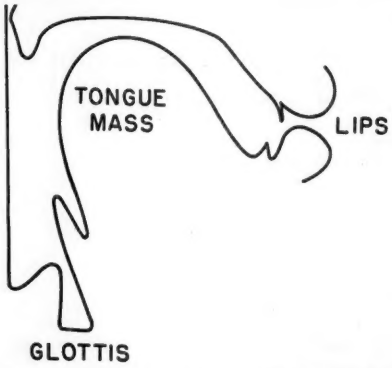

FIGURE 1. Schematized midsagittal section through the vocal tract during the production of a vowel. Adapted from Wendahl (*43*).

following the usual conventions of electric current theory.[1]

When one end of an acoustic tube such as the vocal tract is open, the effect of this open end on the sound in the tube can be represented by a radiation impedance. At low frequencies this radiation impedance may be represented by a resistance $\rho c/A$ in parallel with a small acoustic mass $M_r \cong 0.4\ \rho/\sqrt{A}$, where A is the cross-sectional area, ρ is the density of air, and c is the velocity of sound. In the study of speech sounds, the experimenter usually is interested in the sound pressure p_r measured at some distance r from the mouth. If $U_o(j\omega)$ represents the Fourier spectrum of the volume velocity at the mouth opening, where ω is the radian frequency, then at low frequencies (below, say, 5 000 cps) the relation that describes the radiation of sound from the mouth is approximately that for a 'simple source' (27, pp. 312 ff.):

$$R(j\omega) = p_r(j\omega)/U_o(j\omega) = j\omega\rho/(4\pi r). \quad (1)$$

Of particular interest is the factor of ω in the numerator, indicating a radiation characteristic $\left|\frac{p_r(j\omega)}{U_o(j\omega)}\right|$ that rises at 6 db per octave.

In Figure 1 is shown a schematized midsagittal section through the vocal tract during the production of a vowel. The excitation of the tract is a quasi-periodic series of pulses of air that pass through the glottis during the open phases of the vocal-fold vibratory cycle. A typical waveform of the volume

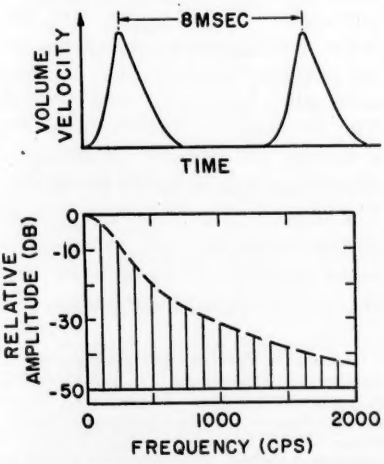

FIGURE 2. A typical waveform of the volume velocity of the glottal output for a fundamental frequency of 125 cps, and a Fourier spectrum corresponding to this type of waveform. The dashed curve describes the envelope of the line spectrum. The slope of the spectrum envelope at low frequencies is derived from Fourier analysis of quasi-triangular waveforms.

[1]See, for example, E. A. Guillemin, *Introductory Circuit Theory*. New York: Wiley, 1953.

velocity as a function of time is shown in Figure 2, along with its corresponding Fourier spectrum. The general shape of the volume velocity waveform is not unlike that of the waveform of the area of the glottis opening as a function of time (*11*). The duration and shape of the pulses shown in Figure 2 are similar to that derived from study of the larynx in action (*33, 39*). It can be demonstrated that this volume velocity waveform $U_s(t)$ is relatively independent of the vocal-tract configuration (*40, 42*), that is, is more or less independent of the acoustic impedance looking into the vocal tract from the glottis, and consequently the internal impedance of the volume velocity source can be considered to be high. The Fourier spectrum of U_s, assuming a periodic waveform, is a line spectrum with components at multiples of the fundamental frequency. At frequencies above about 250 cps (for a typical male voice) the magnitude of these components decreases with increasing frequency at a rate of about 12 db per octave, that is, the spectrum 'envelope' of $|U_s(j\omega)|$ is roughly proportional to ω^{-2}. Below 250 cps, the downward slope of the spectrum envelope is less steep. This low-frequency behavior of the spectrum envelope is predicted from Fourier analysis of triangular waveforms of the type shown in Figure 2.

The shape of the spectrum shown in Figure 2 is typical of the glottal output for conversational speech. The slope of the spectrum envelope at high frequencies can deviate from that of Figure 2 as vocal effort is changed (*24*). Furthermore, irregularities are present in the spectrum shape (*11, 26*), particularly when the spectrum of a single glottal pulse is considered.

As a result of the excitation at the glottis, a volume velocity $U_o(t)$ exists at the mouth opening. If $U_o(j\omega)$ is the Fourier spectrum of the output volume velocity, and $U_s(j\omega)$ the spectrum of the input volume velocity, then a transfer ratio $T(j\omega) = U_o(j\omega)/U_s(j\omega)$ can be defined. In general this transfer function is characterized by a number of resonances or poles, and varies markedly as the configuration of the vocal tract changes.

The above remarks may be summarized by saying that the Fourier spectrum of the sound pressure p_r measured at a distance from the lips during vowel production may be considered as the product of three terms:

$$p_r(j\omega) = U_s(j\omega) \cdot T(j\omega) \cdot R(j\omega) \quad (2)$$

where $R(j\omega)$ is a factor that accounts for radiation from the lips as given in Equation 1. Each term in this product has a phase and an amplitude, each of which is a function of frequency. Usually the experimenter is concerned only with the amplitude spectrum, in which case the magnitude of each term in the product is taken. In general, $U_s(j\omega)$ and $R(j\omega)$ are independent of the articulatory configurations, whereas $T(j\omega)$ is highly dependent upon the vocal-tract shape, and thus varies considerably from vowel to vowel.

Lumped-Circuit Approximation. A rough approximation to $T(j\omega)$ may be obtained if the vocal tract is viewed as a lumped circuit, that is, if the dimensions of the vocal tract are considered to be small compared with a wavelength in the frequency range of interest. Figure 1 shows a typical configuration for which this approximation

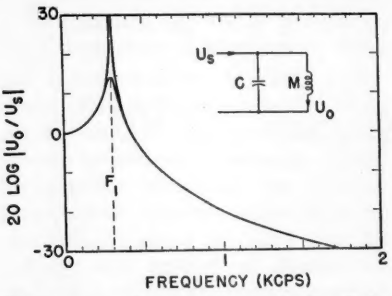

FIGURE 3. A plot of the magnitude of the transfer ratio (in db) as a function of frequency for a one-resonator lumped-circuit approximation of the vocal tract, together with an equivalent lossless circuit. For the ideal lossless case where there is no resistance in the circuit, the curve tends to infinity at the resonant frequency F_1; in realizable circuits with small amounts of dissipation the curve has a finite peak at approximately the same frequency, as shown.

is valid at low frequencies. The assumption of lumped-circuit elements is not unreasonable, since at 300 cps the wavelength is about 100 cm and the length of the vocal tract for an average male is about 17 cm. An equivalent circuit for this configuration is shown in Figure 3, together with a plot of the transfer ratio (in decibels) as a function of frequency. The volume of the tract is represented by C, and the narrow mouth opening (including the radiation impedance) by M. In the ideal lossless case, there is no resistance R in the circuit, and the transfer ratio for this circuit tends to infinity at frequency $F_1 = 1/(2\pi\sqrt{MC})$. Small amounts of dissipation always are present, however, and, consequently, the transfer ratio will have a finite peak at approximately the same frequency. The figure shows curves for the theoretical lossless case and for the case in which the dissipation is typical of that found in the vocal tract.

A typical value for the volume V of the tract between lips and glottis is about 50 cm^3, so that $C = V/\rho c^2 = 3.5 \times 10^{-5}$ cm^5/dyne. For this particular configuration the length l of the mouth opening is about 2 cm and has an average cross-sectional area A of about 0.3 cm^2, so that $M = \rho l/A = 8.0 \times 10^{-3}$ gm/cm^4. Thus $F_1 \cong 300$ cps, a value near the observed frequency of the lowest resonance for the vowel /u/ as spoken by male voices.

If a small amount of dissipation is included in the equivalent circuit of Figure 3, it can be shown from linear circuit theory that the transfer function can be written

$$T_1(j\omega) = \frac{U_o(j\omega)}{U_s(j\omega)} = \frac{s_1 s_1^*}{(j\omega - s_1)\ (j\omega - s_1^*)} \tag{3}$$

where $s_1 = \sigma_1 + j\omega_1$, $s_1^* = \sigma_1 - j\omega_1$, $\omega_1 = 2\pi F_1$ and σ_1 is a constant that depends on the amount of dissipation. When the amount of dissipation is small, $\sigma_1 \ll \omega_1$ and the half-power bandwidth of the resonance is σ_1/π cps. The complex numbers s_1 and s_1^* are often called the *poles* of the transfer function. Under the assumption $\sigma_1 \ll \omega_1$, the magnitude of the transfer function is

$$|T_1(j\omega)| = \left|\frac{U_o(j\omega)}{U_s(j\omega)}\right| \cong \frac{\omega_1^2}{(\omega+\omega_1)\ [(\omega-\omega_1)^2 + \sigma_1^2]^{1/2}}. \tag{4}$$

This relation was used to plot the transfer ratio in Figure 3.

The transfer function of the vocal-tract configuration represented by the equivalent circuit in Figure 3 can be

described in any of three equivalent ways: (a) the volume of the tract and the length and area of the lip opening (together with an appropriate damping constant) can be specified; (b) the values of C and M (and the resistance) in the equivalent circuit can be specified; or, (c) the resonant frequency ω_1 and the damping constant σ_1 can be specified. From any one of these specifications the entire resonance curve in Figure 3 can be described at all frequencies for which the approximations stated above are valid. If the previous statement that the spectrum envelope of the source and the radiation characteristic are relatively invariant is accepted, then it can be asserted that specification of the resonant frequency and bandwidth (or damping constant) permits the construction of the entire spectrum envelope for the vowel. This conclusion will be of particular significance when more complicated models for the vocal tract are discussed.

A one-resonator approximation to the vocal tract is rather unrealistic since it is valid only for frequencies below about 300 cps. A vocal-tract model consisting of more than one resonator would be valid over a frequency range for which *each* resonator is small compared to the wavelength. A representation of the vocal tract by two resonators, which might be valid up to a frequency of about 1 000 cps, is shown in Figure 4 along with a plot of the transfer function. The transfer function is now the product of two terms of the type shown in Equations 3 and 4. In this case, the transfer function exhibits two resonances; each resonant frequency is dependent upon the volumes of both resonators and on the dimensions of both constrictions in the model. The extent to which a given resonance is affiliated with a particular cavity depends upon the amount of coupling between the cavities, that is, upon the sizes of the constrictions. For vocal-tract configurations appropriate to vowel production, it is generally not valid to assign resonant frequencies exclusively to particular cavities (*3*, p. 93, *5*, *10*, pp. 284 ff.).

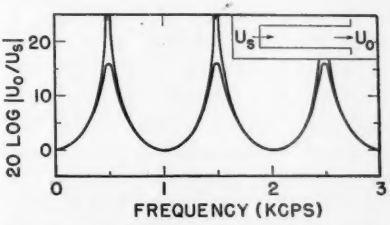

FIGURE 5. A plot of the magnitude of the transfer ratio (in db) as a function of frequency for a distributed (transmission line) representation of an acoustic tube. As shown, the tube is of uniform cross-sectional area and is open at one end; its length is 17 cm. The curve has infinite peaks at resonant frequencies for the ideal lossless case, and peaks of finite amplitude for the slightly dissipative case, as shown. The half-power bandwidth of all resonances was assumed to be 100 cps.

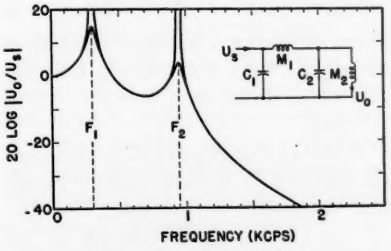

FIGURE 4. A plot of the magnitude of the transfer ratio (in db) as a function of frequency for a two-resonator lumped-circuit approximation of the vocal tract, together with an equivalent lossless circuit. Transfer ratios for the lossless case and the slightly dissipative case are shown (see Figure 3).

Transmission-Line Description. A more general description of the vocal tract that is accurate over a wide frequency range considers the tract as a distributed system or transmission line in which one-dimensional plane waves propagate. In order to explicate this approach it is convenient first to consider a vocal-tract configuration in which the cross-sectional area is constant and in which the radiation impedance is negligible. This provides a uniform acoustic tube driven at one end by a volume velocity U_s and terminated in a short circuit through which volume velocity U_o flows. The situation is illustrated in Figure 5; the articulation of the schwa vowel is similar to this uniform configuration.

Transmission-line theory must be used to compute the transfer function for the uniform configuration, whereas lumped-circuit theory was adequate in the situation where the dimensions of the configuration were small compared with a wavelength. When an acoustic tube is considered as a transmission line, the acoustic disturbances in the tube are viewed as being composed of plane sound waves propagating in both directions. Such a tube has, in theory, an infinite number of resonances, rather than just one resonance as was the case for the simple resonator in Figure 3. The contribution of each resonance to the transfer function of the tube has the same form as that given in Equations 3 and 4. To account for all the resonances it is necessary to take the product of an infinite number of factors like $T_1(j\omega)$ in Equations 3 or 4. Each factor is characterized, however, by a different pair of poles, that is, by a different resonant frequency and a different damping constant. Thus

$$T(j\omega) = \frac{U_o}{U_s} = \frac{s_1 s_1^*}{(j\omega - s_1)\ (j\omega - s_1^*)} \cdot \frac{s_2 s_2^*}{(j\omega - s_2)\ (j\omega - s_2^*)} \cdot \cdots \cdot \frac{s_n s_n^*}{(j\omega - s_n)\ (j\omega - s_n^*)} \cdot \cdots \qquad (5)$$

where $s_n = \sigma_n + j\omega_n$.

In the case of the uniform-tube model of the vocal tract, if end effects are neglected, the various resonant frequencies $f_n = \omega_n/2\pi$ are odd multiples of a lowest natural frequency, that is, the resonances for the familiar situation of a pipe open at one end and closed at the other. In this case, therefore, $\omega_n = (2n + 1)\omega_1$, where n is an integer. The lowest natural frequency $\omega_1/2\pi$ occurs when the length l of the tube is one-quarter wavelength. Since the wavelength λ is given by $\lambda = c/f$, where f is the frequency and c is the velocity of propagation of sound, then

$$\omega_n = (2n + 1)\frac{\pi c}{2l},$$

$$\text{or } f_n = (2n + 1)\frac{c}{4l}.$$

For the case of a uniform vocal tract of length 17 cm, the resonant frequencies occur at about 500, 1 500, 2 500, . . . cps.

A plot of the magnitude of the transfer function in decibels (similar to the plot in Figure 3 for a single resonance) for the uniform tube of length 17 cm can be constructed by *adding* together an infinite number of curves each similar to that in Figure 3, with resonant frequencies at 500, 1 500, 2 500, . . . cps. The result of such a construction, assuming resonance bandwidths of 100

cps, is shown in Figure 5. The important features of this plot are that the value of $|T(j\omega)|$ is the same at each resonant frequency, and that $|T(j\omega)|$ is approximately unity at zero frequency and at frequencies midway between the resonant frequencies, that is, at 1 000, 2 000, 3 000, . . . cps in this case.

The uniform tube is an idealized configuration that may not occur precisely in practice. Several conclusions may be drawn from a discussion of the properties of this configuration, however, and these conclusions will apply, in general, to other configurations. (a) The transfer function $T(j\omega)$ is characterized by an infinite number of resonances; on the average, these resonances occur every $c/2l$ cps (or approximately every 1 000 cps for male voices). (b) Lengthening the vocal tract tends to lower the frequencies of all resonances; shortening the tract increases the frequencies of all resonances.

In order to study resonant frequencies for a particular vowel configuration for which the cross-sectional area of the vocal tract is not uniform, the configuration can be visualized as a perturbation of the uniform tube. (It is assumed throughout the discussion that there is no coupling to the nasal cavities.) Starting with the uniform tube with resonant frequencies at, say, 500, 1 500, 2 500, . . . cps, the shape is distorted gradually until the configuration approaches that of the vowel under study. As this perturbation process is carried out, the resonant frequencies gradually shift their positions and in the limit settle at new values. The number of resonances and their average spacing will not change, however, if the vocal-tract length does not change. For a configuration appropriate for the production of /ɑ/, for example, typical values of the resonant frequencies are 800, 1 200, 2 500, etc. (*19*). Thus, for a general vowel configuration, Equation 5 can still be used to specify the vocal-tract transfer function, but the values of ω_n and σ_n must be selected to correspond to the resonant frequencies and bandwidths for that particular configuration. The values of $\omega_1, \omega_2, \ldots$ for a particular vocal-tract configuration may be viewed as the natural frequencies of free vibration for that configuration, and they are the same, independent of how the system is excited. Once the values of the resonant frequencies and bandwidths are known, then these values can be used in Equation 5 to compute the *entire* transfer function $T(j\omega) = U_o/U_s$ for *all frequencies.*

The relations between the configuration of the vocal tract and the resonant frequencies and bandwidths have been the subject of study for many years (*3, 4, 5, 10, 36, 41*). When the cross-sectional area of the vocal tract is known at all points along its length, calculations of the resonant frequencies can be made, but such calculations are complex, and, therefore, computational aids such as electrical analog devices and digital computers have been used to establish the relations (*5, 10, 36*). While it is not the purpose of this paper to discuss these relations in detail, one general relation will, however, be noted since it has a bearing on the ensuing discussion. This relation is the following: the frequency of the first resonance tends to decrease as the cross-sectional area at some point along the vocal tract decreases, that is, as the

vocal tract becomes more constricted (except when the constriction occurs within a few centimeters of the glottis). This result has been discussed in quantitative terms elsewhere (*36*), but can easily be verified if reference is made to the analog circuits shown in Figures 3 or 4, which are reasonably valid representations of the acoustic behavior of the vocal tract at low frequencies. In these circuits a vocal-tract constriction is represented by an acoustic mass M whose magnitude is inversely proportional to the cross-sectional area of the constriction. In the case of Figure 3, therefore, M becomes larger as the area of the constriction decreases, and thus the frequency of the first resonance $F_1 = 1/(2\pi\sqrt{MC})$ decreases. In the case of Figure 4, which corresponds to a two-cavity idealization of the vocal-tract configuration, it can be shown that the frequency F_1 of the first resonance decreases as M_2 becomes large, and also decreases as M_1 becomes large, provided the constriction with which M_1 is associated is not too close to the glottis. An increase in M_1 corresponds to a decrease in the cross-sectional area of the constriction separating the two cavities, whereas an increase in M_2 corresponds to a decrease in the cross-sectional area of the anterior end of the vocal tract.

Properties of the Spectrum Envelope. It has been shown in Equation 2 above that the spectrum of the sound pressure p_r measured at a distance r in front of the lips is the product of three terms (or the sum of three terms if each is expressed in decibels): a source spectrum $U_s(j\omega)$, a radiation characteristic $R(j\omega)$, and a transfer function $T(j\omega)$ The first two terms are both almost independent of the articulatory

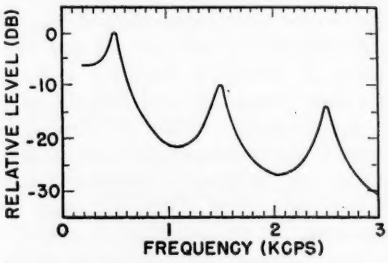

FIGURE 6. A vowel spectrum envelope constructed by adding together the transfer function of Figure 5, the spectrum envelope of the glottal source shown in Figure 2, and a radiation characteristic rising at 6 db/octave.

configuration, while the last is dependent on the configuration and is characterized by a number of resonances or poles. The spectrum envelope of a vowel can be constructed, therefore, simply by adding to the 20 log $|U_o/U_s|$ curve of Figure 5 the spectrum envelope of U_s, which has a form similar to that shown in the lower part of Figure 2, plus the radiation characteristic, which rises at 6 db per octave in the frequency range of interest. An over-all vowel spectrum envelope constructed in this way for the uniform vocal-tract configuration is shown in Figure 6. For a glottal excitation of fixed frequency the spectrum actually is a line spectrum, the spacing between components being equal to the fundamental frequency.

When the vocal-tract configuration differs from the uniform-tube idealization, the frequencies of the resonances and hence the frequencies at which there are peaks in the spectrum envelope, shift to positions different from those shown in Figure 6. If the frequencies and bandwidths of the resonances for the new configuration are known, then the transfer

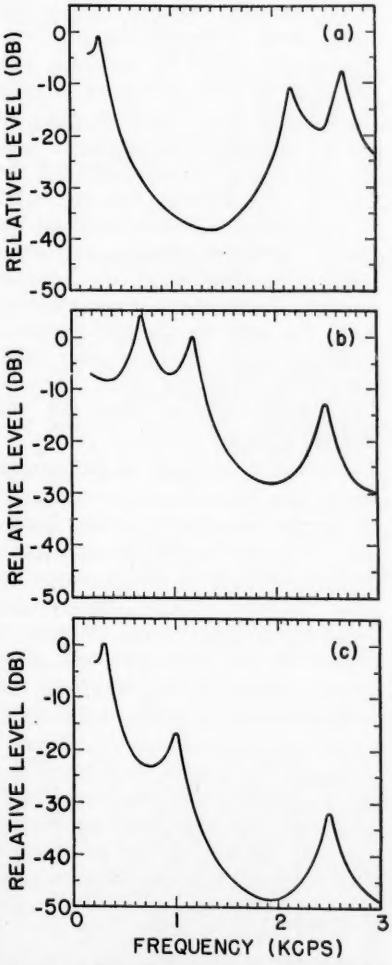

FIGURE 7. Computed spectrum envelopes approximating the vowels /i/, /ɑ/, and /u/. The half-power bandwidths of all resonances were assumed to be 100 cps.

function $T(j\omega)$ can be computed using Equation 5 in the manner discussed above, and the entire spectrum envelope can again be constructed by adding to $T(j\omega)$ (in decibels) the radiation characteristic and the spectrum envelope of the source. This procedure has been used to construct the three spectrum envelope curves shown in Figure 7. In order to simplify the calculations, the half-power bandwidths of all resonances again were assumed to be 100 cps, a value that is not greatly different from the bandwidths of the first three resonances for spoken vowels (*2*, *18*, *23*). The three curves correspond roughly to the spectrum envelopes for /i/, /ɑ/, and /u/.

The curves in Figures 6 and 7 demonstrate that the relative amplitudes of the spectral peaks vary markedly depending on the frequencies of the resonances. Consider, for example, spectra (a) and (c) in Figure 7, in which the frequencies of the first and third resonances are roughly the same but the second resonance is at 2 200 cps in one case and 1 000 cps in the other. The amplitude of the third spectral peak is about 24 db higher in spectrum (a) than in spectrum (c) as a result of the difference in the frequencies of the second resonances.

The fact that the amplitudes of the spectral peaks in vowel spectra are predictable when the resonant frequencies are known has been discussed in some detail by Fant (*8*). From theoretical considerations, Fant predicted the amplitudes of the first three spectral peaks of selected vowels and showed that these calculated levels were in good agreement with previously reported measurements of the average levels of the spectral peaks of spoken English and Swedish vowels.

Some insight into the causes for the changes in the amplitudes of the spectral peaks with changes in the resonant frequencies can be gained from re-

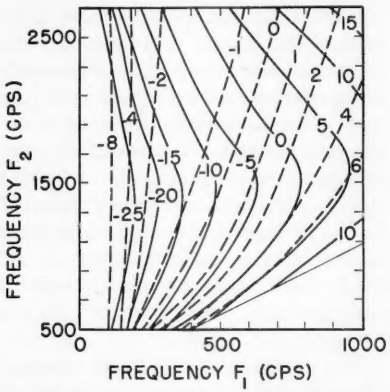

FIGURE 8. Computed isoamplitude contours of the first resonance peak (dashed curves) and second resonance peak (solid curves) for vowel spectrum envelopes as a function of the frequencies of the first and second resonances. Amplitudes are given in decibels relative to the level of the first resonance peak when $F_1 = 500$ cps, $F_2 = 1\,500$ cps, $F_3 = 2\,500$ cps, etc. See text for assumptions used in the calculations and for corrections to be applied when the assumptions are not met.

examination of the transfer function for the two-resonator approximation of the vocal tract. It is recalled that the transfer function in Figure 4 was constructed by adding two simple resonance curves of the type shown in Figure 3. In that example the resonant frequency for one component curve was 300 cps and the resonant frequency for the other was 950 cps. If now the frequency F_2 of the second resonance is shifted upwards while the first resonant frequency F_1 is held fixed, then the amplitude of the second peak in the composite curve will decrease. Likewise, if F_2 is held fixed while F_1 is shifted upwards, then the amplitude of the second peak in the composite curve will increase. There will be concomitant changes in the amplitude of the first resonance peak in both these cases, but these changes will be relatively small. Although the amplitude relations just noted are discussed with reference to the vocal-tract transfer function, the same relations apply to the over-all spectrum envelope, since the source spectrum envelope and the radiation characteristic that are added to the transfer function to obtain the over-all spectrum envelope are independent of changes in the transfer function. Furthermore, these relations apply not only to the two-resonator model but also to the more exact transmission-line model, for which the transfer function is constructed by the addition of many resonance curves.

Calculations of Levels of Resonances. Up to this point it has been assumed tacitly that the spectra under discussion were characterized by resonances, each of which gives rise to a separate peak or prominence at the resonant frequency. When resonant frequencies are sufficiently close, however, they are not necessarily identical with the frequencies of the peaks in the spec-

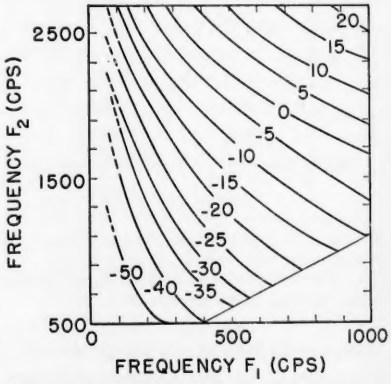

FIGURE 9. Computed isoamplitude contours of the third resonance peak for vowel spectrum envelopes as a function of the frequencies of the first two resonances (see legend Figure 8).

trum. For example, when two resonances with bandwidths of about 100 cps are about 100 cps apart, the spectrum envelope may show only one prominence; the frequency of the peak will be somewhere between the two resonant frequencies. In the discussion that follows, the levels of the resonances will be defined to be the levels of the spectral envelope at the frequencies of the resonances (rather than at the spectral peaks).

The quantitative relations among the levels of the three lowest resonances for a range of values of the frequencies of the first two resonances can be calculated by means of the relations discussed above. Such calculations have been carried out by means of a digital computer, and are depicted by the contour plots shown in Figures 8 and 9. Along any one contour the level of a particular resonance remains constant at the indicated value. In Figure 8, the dashed contours represent loci of constant amplitude of the first resonance, while the other contours represent corresponding loci for the second resonance; the contours in Figure 9 pertain to the third resonance. In both figures the amplitude levels are given in decibels relative to the level of the first resonance when $F_1 = 500$ cps, $F_2 = 1\,500$ cps, $F_3 = 2\,500$ cps, etc.

The following constraints were applied to the generation of the data in Figures 8 and 9. The bandwidths of all resonances were 100 cps. The spectrum envelope of the glottal output was that shown in Figure 2, and the over-all level of the excitation was held constant. The third and higher resonances were held constant at 2 500 cps, 3 500 cps, 4 500 cps, etc., except that $F_3 = F_2 + 500$ cps when F_2 exceeded 2 000 cps and $F_4 = F_3 + 500$ cps when F_3 exceeded 3 000 cps.

The use of the contours is made clear by considering the spectrum envelope associated with the uniform tube, as shown in Figure 6. If the level of the first resonance at 500 cps is the zero db reference, then the level of the second resonance is about −9.5 db and that of the third resonance is about −15 db. In Figure 8, the intersection of $F_1 = 500$ cps and $F_2 = 1\,500$ cps gives levels of zero db and about −9.5 db, respectively; the same operation in Figure 9 provides a level of about −15 db for the third resonance. Similarly the relative levels of the resonances of the three samples in Figure 7 may be read from the contours.

In general the contour plots indicate that the level of a given resonance is influenced strongly by the frequencies of the lower resonances. Thus the level of the second resonance at a given frequency drops sharply when the frequency of the first resonance is decreased; similarly the level of the third resonance is influenced strongly by the frequencies of both the first and second resonances. If the frequencies of two resonances are close together, the levels of both are relatively high, as when F_2 is below 1 500 cps and F_1 is above 500 cps, or when F_2 is above 2 000 cps and F_3 is only 500 cps higher.

Since the contours in Figures 8 and 9 assume that the bandwidths of the various resonances are always 100 cps, a word must be said about the effect of variations from this value. If the bandwidth B of a given resonance differs from 100 cps, then $20 \log_{10} (100/B)$ should be added to the level read from Figure 8 or 9 for that resonance. For

example, if the bandwidth of the second resonance of the vowel shown in Figure 6 is narrowed to 70 cps, the correction to be applied is +3 db, and hence the level of the second resonance becomes —6.5 db instead of —9.5 db.

Some Implications of the Theory

A number of measurements pertaining to amplitudes and spectra of speech sounds have been reported in the literature. In particular, studies have been made of frequencies and amplitudes of vowel formants, amplitude relations and formant transitions within syllables, and relative intensities of vowels and consonants. In general, acoustic data of this type have not been organized within a cohesive theoretical framework, except in the technical monograph by Fant which appeared recently (*10*). The acoustical theory of vowel production outlined above provides such a framework for the discussion of amplitude relations in syllabic nuclei.

Relative Intensities of Vowels. It has long been recognized that different vowels generated with the same vocal effort have different over-all levels (*1*, 7, *32*). The range of over-all levels for the common vowels of American English is roughly 4 to 5 db, with /i/ and /u/ having the lowest levels and /æ/, /ɑ/, and /ɔ/ the highest levels.

An attempt to relate these data to articulation was made by Fairbanks (*6*), who postulated that vowel intensity should be correlated with the anterior opening of the vocal conduit, and demonstrated such a correlation between two sets of published data. Figure 8 shows that the over-all intensity of a vowel is determined largely by the frequency of the first vowel resonance since the level of that resonance is always greater than that of

TABLE 1. Calculation of the over-all relative intensities of four vowels. The column headings are as follows: *A*, average frequencies of the first and second vowel resonances, in cps (*19*); *B*, relative levels of resonance peaks, in db, derived from Figure 8; *C*, half-power bandwidths of resonances, in cps (*19*); *D*, corrections 10 $\log_{10}(100/B)$ db to account for deviation of bandwidths from 100 cps; *E*, relative contributions of resonances to over-all intensity of vowel, in db; *F*, relative intensity of vowels, in db. The assumptions regarding higher formants and glottal spectrum are the same as those used in constructing Figures 8 and 9.

Vowel	*A*	*B*	*C*	*D*	*E*	*F*
i	F_1 = 300	− 1.9	50	3.0	1.1	1.3
	F_2 = 2 260	−11.0	120	−0.8	−11.8	
æ	F_1 = 730	2.0	100		2.0	3.8
	F_2 = 1 650	− 1.0	100		− 1.0	
ɑ	F_1 = 720	4.2	130	−1.1	3.1	5.6
	F_2 = 1 190	1.0	80	1.0	2.0	
u	F_1 = 320	− 1.1	60	2.2	1.1	1.2
	F_2 = 1 110	−16.0	100		−16.0	

higher resonances. But the frequency of the first resonance is closely related to the size of the mouth opening (see *supra* and *36*), and, therefore, the positive correlation described by Fairbanks can be considered to be a consequence of the acoustical theory.

Quantitative prediction of the over-all vowel intensities can be made from the contours of Figure 8. The procedure is first to find the relative levels of the first two resonance peaks, knowing the frequencies of these resonances. For resonance bandwidths of 100 cps, the relative levels given in the contours are identical to the contributions of the individual resonances to the over-all vowel intensity. If, however, the bandwidth B of a resonance is different from 100 cps, a correction of 10 $\log_{10}$ $(100/B)$ must be added to determine the contribution of that resonance to the over-all vowel intensity.[2] The over-all relative intensity of the vowel is obtained by summing the contributions of the first two resonances (the contribution of higher resonances will be very small and can be neglected).

Typical calculations for four vowels are shown in Table 1. The values of resonant frequencies and bandwidths represent means for three male talkers who generated the vowels in a large number of consonant contexts. The measurements were made with the aid of a digital computer using spectrum matching techniques, and refer to spectral samples appearing centrally in the temporal course of the vowel (*19*). The computed values of relative intensity in the right-hand column of the table compare well to previously published measurements of vowel intensity, the range from /u/ to /ɑ/ being 4.4 db. For example, from the data of Sacia and Beck (*32*) a list of these four vowels in order of intensity ('average peak power') would be /uiæɑ/, with 4.8 db difference between the extreme vowels; other experimenters report similar data (*1*, 7).

Amplitude Relations within the Syllable. The motoric description of speech production espoused by Stetson (*35*) defines the so-called releasing and arresting actions of consonants (or of other muscular activity) to constitute the boundaries of the syllable. In a symmetric consonant-vowel-consonant (CVC) syllable, the initial C that releases the syllable is characterized by a vocal-tract constriction that gradually (or abruptly) increases in size, while the final C that arrests the syllable is characterized by a gradual (or abrupt) decrease in the size of a constriction in the vocal tract. During the temporal course of this activity, the vocal tract may be excited by one or more acoustic sources, but typically the central portion of the syllable is characterized by glottal excitation or voice. It has already been noted above that the frequency of the first resonance decreases as the vocal tract becomes more constricted. The amplitude relations depicted in Figure 8 demonstrate, moreover, that the amplitude of the first resonance peak—and consequently the over-all amplitude of the vowel—decreases as F_1 decreases. The rate of decrease becomes more rapid as F_1 falls below 300 cps, that is, as F_1

[2]The correction factor to determine the contribution of a resonance to over-all intensity is different from the correction used to find the level of the resonance peak. The over-all intensity is determined by the area under the spectrum envelope, and is a function, therefore, both of the height of the resonance peak and of its width.

assumes values associated with vocal-tract configurations more appropriate to consonant production than vowel production (*37*). In other words, during the course of a typical CVC syllable the acoustical theory predicts that, while the source excitation remains constant, the over-all intensity will build up to a maximum value in a central (vocalic) portion and then decrease.

Stetson and Hudgins (*35*, pp. 179 ff.) have reported data on amplitude fluctuations within the syllable obtained by simultaneous kymographic and spectrographic recordings. These data, together with descriptions of the typical form of oscillographic and graphic level records (*7*, *17*), demonstrate that the syllable is characterized by an intensity maximum reached during the central portion of the vowel. The acoustical theory of vowel production, therefore, is compatible both with the motoric point of view regarding syllable production and with the classical statements of inherent and relative sonority and syllabic peaks of prominence (*20*). Hence the so-called 'undulation of prominence' (*20*, p. 55) that is perceived by the hearer is a reflection both of the acoustic end-product and of the articulatory events responsible for it.

Spectrum Balance in the Vowel. While the over-all vowel intensities discussed above are related primarily to changes in the first vocal-tract resonance, Figures 8 and 9 also demonstrate wide variations in the levels of the second and third resonance peaks as a function of the frequencies of the first two resonances. The variation in the levels of resonance peaks within the vowels of actual speech is well known (*29*), but the dependence of these variations on articulation was not explained adequately until recently (*8*).

The fact that rigorous relations obtain among the levels of the resonance peaks, the frequencies of the resonances, and the articulatory configuration has a bearing on the formulation of theories of vowel perception. The lack of independence among these factors makes it inappropriate to hypothesize that the perception of a vowel is attributable to any one of them to the exclusion of the others. Independent manipulation of these characteristics in experiments using synthetic speech is to be questioned if the results are to be generalized to explain the perception of natural speech.

The attempts made in the past to characterize a vowel in terms of the frequency locations of spectral prominences have focused attention on an aspect of the physical event that may not be clearly observable (*22*), particularly when two resonances are closely spaced in frequency, a resonance has a broad bandwidth, or the amplitude of a resonance is very low. The theoretical discussions above indicate, however, that the presence of a resonance may be signaled not only by spectral prominences but also by amplitude relations within the spectrum envelope. In the spectrum of a vowel /u/, for example, the third resonance is often below the dynamic range of the measuring equipment, while the first two resonances are sometimes not manifested as separate spectral prominences. When it is understood, however, that a low-amplitude third resonance is a consequence of low-frequency first and second resonances the spectrogram is easily interpreted.

On Defining the Formant. The dis-

cussions above suggest the need for more precise definitions of some of the traditional terms used by linguists, phoneticians, and other students of speech. One such term, conspicuous because of its almost complete absence in this paper to this point, is the word *formant*.

In the literature the term *formant* has been used principally to indicate a concentration of spectral energy in a narrow frequency region of a speech signal. Futhermore, it generally has been applied only to those portions of the speech signal called voiced, that is, characterized by glottal excitation. When sound spectrograms (intensity-frequency-time displays) are made on an instrument using a broad (300 cps) analyzing filter, the formant structure of continuous speech is displayed as a number of more-or-less horizontal 'bars' (*30*). For any given vocalic sound a number of formants may occur in the frequency range 0 to 4 000 cps, but attention is usually focused on the lowest two or three.

When the term *formant* was proposed originally, it was used to designate a natural frequency (charakteristischer Ton) of the vocal cavities, and a so-called inharmonic theory of vowel production was implied (*15*, *16*). Subsequently the term was adopted by the advocates of another theory of production—the harmonic theory—and used to designate the center frequency in a 'tonal domain' contributing to the character of the particular vowel (*38*).

A typical description of a formant was given by Joos (*21*): 'The frequencies corresponding to the centers of the two principal peaks of the [spectrum] profile . . . are called formant 1 and formant 2, respectively.' Potter and Steinberg (*31*), on the other hand, attempted to specify the measurement procedures used in their investigations as follows: '. . . we suspect that the ear deals with something akin to effective pitch centers of loudness of the energy concentrations. For our initial work we have adopted as an approximation of such a center, a weighted average of the frequencies of the formant components.'

The problem of defining the formant was confused further by the attempts of investigators to specify variant and invariant formants in speech spectra. Sovijärvi (*34*), for example, reported finding seven variable and 11 fixed formants and attempted to relate each of them to a cavity resonator in the vocal system. More recently, Ochiai and Fukumura (*28*), in an investigation of voice quality, have discussed the probable role of invariant formants. These investigators have complicated the terminological situation still further by using *formant* to refer to a spectral concentration that is manifested when the vowel spectra of a number of subjects are summed graphically.

In view of this historical resumé, the common usage of the term *formant* leaves several questions unanswered. Should the word be applied to energy concentrations in consonant spectra? If so, is it permissible to apply it to both voiced and voiceless consonants? Is it appropriate to refer to the various energy concentrations in the spectrum of a nasalized vowel or a nasal consonant as formants? How can the frequency of a formant be measured precisely? And so on . . . .

It has been recognized (*10*, *12*, *14*) that the acoustical theory of speech production can provide a precise defi-

nition for the term formant. Following Hermann (*15*), it is proposed that a formant be interpreted as a normal mode of vibration of the vocal tract, and formant frequency be defined as the frequency of such a normal mode of vibration. The term formant is applied to the vocal tract in a manner similar to the way in which *pole* is used to characterize an electric network, and implies, therefore, a complex number consisting of a real part (proportional to the formant bandwidth) and an imaginary part (the formant frequency).

This definition of formant means that the vocal tract has formants regardless of its excitation. During the production of certain sounds (notably the vowels) the formants are manifested in the acoustic output as maxima in the spectra. When the formants are reasonably well separated in frequency, and when their bandwidths are not abnormally wide, the frequencies of the spectral maxima are good measures of the formant frequencies. During the production of other sounds (particularly certain consonants) certain normal modes are only weakly excited and will not be immediately apparent in the output spectra. It can be argued, however, that since the vocal tract executes continuous motions during the production of syllables, the formant frequencies are continuous functions of time (*9*).

Defining the formant in terms of articulation raises certain problems of measurement, since usually only the acoustic signal is available for analysis. Traditional spectrographic procedures for measuring formant frequencies of vowels can often lead to reliable data, however, providing that the constraints imposed by the acoustical theory are kept in mind. A more powerful technique should take into account the effect of a given formant on the entire spectrum shape. Such techniques are under development and will provide data relative to consonant as well as vowel production (*10, 13, 14, 19, 25*). It is interesting to note that, as early as 1936, Lewis (*23*) used a technique of matching simple resonance curves to vowel spectra in the vicinity of spectral maxima, thus applying to his measurements some of the constraints imposed by the acoustic theory.

Summary

A contemporary acoustical theory of vowel production is outlined and certain implications of the theory are discussed. The theory considers a vowel sound to be the result of excitation of a linear acoustic system by a quasi-periodic volume velocity source. The transfer function of the acoustic system is completely described by a number of poles whose frequency locations depend on the vocal-tract configuration. It is shown that the theory is compatible with data relevant to the over-all intensity of vowels, amplitude relations within syllables, and questions of balance in the vowel spectrum. Finally it is proposed that the traditional term *formant* be restricted to mean a normal mode of vibration of the vocal system.

Summario in Interlingua

Un contemporaneo acustic theoria de vocal production es contornate e certe implications de le theoria esse discutite. Le theoria considera un vocal sono esser le resultato de excitation de un linear acustic systema per un quasi-periodic volumine velocitate fonte. Le transfer

function de le acustic systema es describite completemente per un numero de polos cuje frequentia locations depende sur le vocal-tracto configuration. Ille es monstrate que le theoria es compatibile con datos relevante a le supertoto intensitate de vocals, amplitude relations intra syllabas, e questions de balancia in le vocal spectro. Al fin ille es proponite que le traditional vocabulo *forman* esser restringite a significa un normal moda de vibration de le vocal systema.

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Measurement of Adaptation in Stuttering

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The aspect of stuttering behavior which has been studied most frequently perhaps is the adaptation effect, that is, the tendency for the frequency of stuttering to decrease with successive oral readings of the same passage. This phenomenon was first reported by Johnson and Knott (*9*) in 1937, although it appears that Van Riper and Hull (*21*) had observed it as early as 1934.

Measures of adaptation have afforded investigators a readily available criterion for testing the effects on stuttering of different variables such as drugs (*10*), fatigue (*3*), and delayed auditory feedback (*12*). In addition, adaptation both constitutes in part a rationale for stuttering therapies which stress more talking and serves as a model for expected improvement under therapy. Van Riper and Hall (*21*) felt that 'adaptation curves could reflect therapeutic progress' and they speculated that 'if stutterers improved in their over-all ability to adapt to speaking situations, their adaptation rate to a reading situation should show a gain over that shown at the onset of therapy.' Johnson, Darley, and Spriestersbach (*8*, p. 123) state, 'A stutterer who adapts a great deal might be expected perhaps to respond better to therapy than one who shows no "capacity for improvement" —that is, who shows no adaptation or reduction in stuttering—during the five test readings.' Quarrington (*15*) reached the tentative conclusion that for a person who shows high adaptation, one would predict some improvement for any therapeutic process designed to reduce the amount of strong disintegrative emotionality.

Measures of adaptation will no doubt continue to be used as criterion variables and the phenomenon itself will probably continue to play an important role in the study of stuttering. The purposes of this paper are to examine several feasible measures of adaptation and to present aids to their computation. So far as the writers know, two of the measures, the normal deviate and the trend measures, have not previously been suggested.

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Measures of Adaptation

Rank Measure. In their pioneer study, Van Riper and Hull (*21*) used two measures of adaptation. To obtain one, they ranked from 1 to 5 the frequencies of stuttering of each subject in five successive readings and took as the measure of adaptation of the group the mean ranks for each of the five readings.

Although it has rarely been used, this measure has several advantages if only group adaptation is of interest: it makes use of the information from all five readings; it is independent of initial frequency of stuttering and is immediately tractable to analysis of variance by ranks.[1] However, it provides no general information about individual adaptation and permits no satisfactory test of differences in group adaptation under changing conditions. Its use would seem to be limited to description of group adaptation.

Van Riper and Hull obtained their second measure of adaptation by converting the number of words stuttered during each reading into a percentage of the number stuttered during the reading where frequency of stuttering was greatest. This measure is apparently the forerunner of the percentage adaptation measure described below.

Percentage Adaptation Measure. The most commonly used measure of adaptation appears to be that of percentage adaptation (A_p) defined by: $A_p = 100\ (P_i - P_j)\ /\ P_i$, where P_i is the percentage of words stuttered during the ith reading and P_j is the percentage of words stuttered during the jth reading. Usually the same passage is used in all readings and i is taken as one and j as five so that $A_p = 100\ (S_1 - S_5)\ /\ S_1$, where S_1 is the number

[1]When the frequencies of stuttering of N subjects in the five readings are classified in N rows and five columns and the frequencies in each row ranked from 1 to 5, analysis of variance by ranks provides a test of the significance of differences among the means of the columns, the mean ranks of frequencies of stuttering during the successive readings. A test of differences among the N subjects may be made by ranking the frequencies of stuttering from 1 to N for each of the five readings and testing for differences among the N mean ranks. Analysis of variance by ranks was first proposed by Friedman (*6*).

Analysis of variance by ranks provides no test of trend. If a test of trend of the mean ranks for successive readings is desired, one may easily be constructed. Under the hypothesis of no downward trend, the 5! or 120 possible arrangements of the mean ranks are equally likely. If the largest mean rank is assigned a rank of 5, the next largest a rank of 4, and so on, the test consists of comparing the assigned ranks with the order 5, 4, 3, 2, 1. If there is no discrepancy, the hypothesis of no downward trend is discredited at the 1/120 or .008 level, since only one of the 120 arrangements will show no discrepancies. If the discrepancies sum to 2, as would be the case if the mean ranks were in the order 5, 4, 2, 3, 1, the hypothesis is discredited at the .042 level, since only five arrangements show discrepancies which sum to 2 or less. Since this test is nearly equivalent to testing the significance of the familiar rank-order coefficient of correlation of observed mean ranks and the order 5, 4, 3, 2, 1, it is suggested here that the latter be used. There is no need to actually compute the coefficient. The sum of the squared discrepancies Σd^2 significant at the indicated level is:

Σd^2	Significance Level
0	.008
2	.042
4	.067
6	.117

The test for trend is independent of the test for differences among means of columns. Hence, the probabilities from the two tests can be combined, if desired, by means of Fisher's (*5*, pp. 99-101) natural logarithm transformation of probability figures to provide a composite test of the significance of adaptation during the five readings.

of words stuttered during the first reading and S_5 the number stuttered during the fifth.

This simple and intuitively attractive measure has several faults. Quarrington (*16*) and others have found that its correlation with the frequency of stuttering on the initial reading is substantial (*r*s ranging from —.65 to —.40). Of course, this may not necessarily be a fault. There is reason to believe that frequency of stuttering and severity of stuttering, as rated by judges, are substantially related (*17*, *18*, *22*). Van Riper and Hull (*21*) found that 10 severe stutterers as a group showed high initial frequency of stuttering, high end plateaus, and a gradual degree of adaptation, while 10 mild stutterers as a group showed low initial frequency, low end plateaus, and rapid adaptation. They also noticed that the severe stutterers as a group required more readings to reach their plateaus than did the mild stutterers. Thus it may be that both initial frequency and severity of stuttering are in fact negatively correlated with adaptation and that, as Van Riper and Hull conjectured, adaptation may be useful in gauging severity of stuttering. However, the relationship or its absence will be better demonstrated when the two are measured independently.

TABLE 1. Distributions of proportions of words stuttered on first and fifth readings of a 180-word passage by 89 subjects and distributions of the arc sine transformations of the proportions.

Proportion	*Frequency*		*Arc Sine*	*Frequency*	
	First Reading	*Fifth Reading*		*First Reading*	*Fifth Reading*
.65 to .69	1	1	1.95 to 2.07	1	
.60 to .64	2	1	1.82 to 1.94		2
.55 to .59		1	1.69 to 1.81	2	1
.50 to .54	1		1.56 to 1.68	1	
.45 to .49	3		1.43 to 1.55	3	
.40 to .44			1.30 to 1.42	1	2
.35 to .39	2	3	1.17 to 1.29	4	5
.30 to .34	5	4	1.04 to 1.16	7	1
.25 to .29	5	1	.91 to 1.03	13	2
.20 to .24	13	1	.78 to .90	7	9
.15 to .19	7	7	.65 to .77	5	8
.10 to .14	5	14	.52 to .64	12	7
.05 to .09	19	10	.39 to .51	10	6
.00 to .04	26	46	.26 to .38	13	17
			.13 to .25	10	15
			.00 to .12		14
*Skewness,** g_1	1.44	2.29		.72	1.19
*Kurtosis,** g_2	4.56	8.48		3.04	4.10

*Based on the moments of the distribution. When a distribution is symmetrical with normal peakedness, $g_1 = 0$ and $g_2 = 3$. When sample size is 89 and the population normal, the 90% confidence limits for population g_1 are —.40 and .40, and for population g_2, 2.33 and 3.80. The 98% limits are —.60 and .60, and 2.16 and 4.44, respectively.

The percentage adaptation measure probably is affected by the diurnal variation in frequency of stuttering and its reliability therefore lowered. Quarrington (*16*) points out that 'to employ a measure associated with initial frequency incorporates a source of unreliability in measures of adaptation.'

The percentage adaptation measure has two definite statistical limitations. In studies involving group data, it is not clear how to average percentage adaptation scores. An unweighted mean is distorted by the scores of low-initial-frequency, high-percentage-adaptation subjects; a weighted mean all but buries the performance of such subjects. The matter is related, of course, to the difficulty of working with percentages having widely different bases.

The second limitation arises in the distribution of the percentage adaptation measure in a group. (The distribution of the measure in a group of 89 subjects is shown in the first column of Table 2.) The writers have ex-

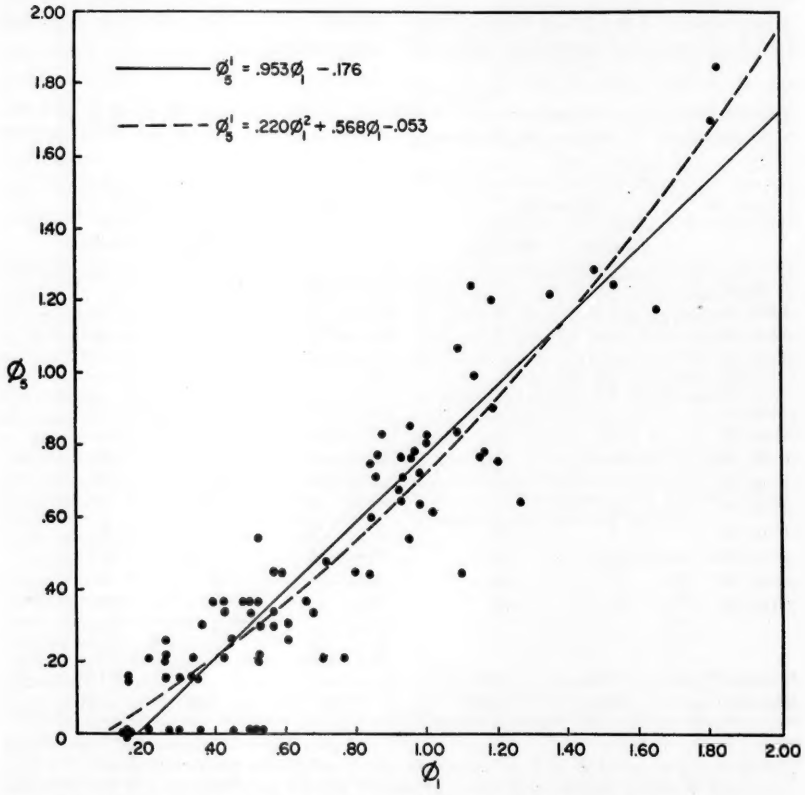

FIGURE 1. First and second degree lines of regression of ϕ_s on ϕ_1 for a sample of 89 stutterers.

amined six additional distributions of samples varying in size from 20 to 51, and in all cases the distributions were irregularly rectangular and, in all cases except one, bimodal with the modes at or near the extremes. Such distributions

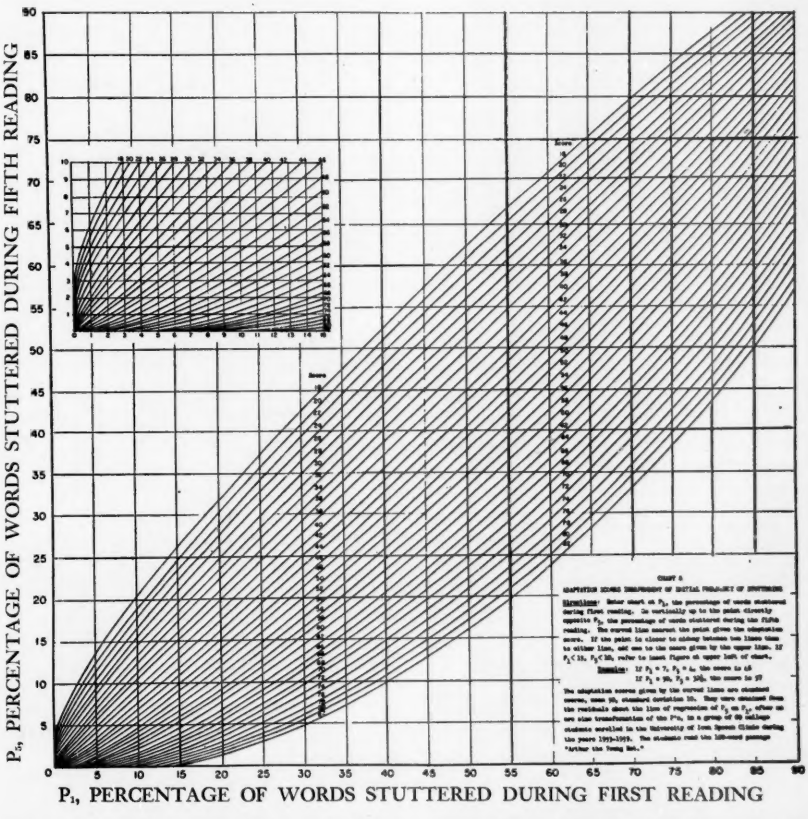

FIGURE 2. A reproduction of chart of adaptation scores independent of initial frequency of stuttering. Directions for use of the chart, printed lower right, are as follows: 'Enter chart at P_1, the percentage of words stuttered during first reading. Go vertically up to the point directly opposite P_5, the percentage of words stuttered during the fifth reading. The curved line nearest the point gives the adaptation score. If the point is closer to midway between two lines than to either line, add one to the score given by the upper line. If $P_1 < 15$, $P_5 < 10$, refer to inset figure at upper left of chart. Examples: if $P_1 = 7$, $P_5 = 4$, the score is 46; if $P_1 = 50$, $P_5 = 32\frac{1}{2}$, the score is 57. The adaptation scores given by the curved lines are standard scores, mean 50, standard deviation 10. They were obtained from the residuals about the line of regression of P_5 on P_1, after an arc sine transformation of the Ps, in a group of 89 college students enrolled in the University of Iowa Speech Clinic during the years 1955-1959. The students read the 180-word passage "Arthur the Young Rat."' (Single copies of the original chart may be obtained by writing to the Speech Clinic, University of Iowa, Iowa City, Iowa.)

TABLE 2. Distributions of four measures of adaptation in a sample of 89 stutterers.

Percentage Measure (A_p)		*Residual Measure* ($A\phi$)		*Normal Deviate Measure* (A_z)		*Trend Measure* (A_t)	
Score	*f*	*Score*	*f*	*Score*	*f*	*Score*	*f*
96 to 103	14	76 to 79	1	5.85 to 6.39	2	1.04 to 1.11	1
88 to 95	2	72 to 75	2	5.30 to 5.84	1	.96 to 1.03	
80 to 87	6	68 to 71	3	4.75 to 5.29		.88 to .95	
72 to 79	5	64 to 67	3	4.20 to 4.74	6	.80 to .87	2
64 to 71	9	60 to 63	6	3.65 to 4.19	1	.72 to .79	
56 to 63	3	56 to 59	9	3.10 to 3.64	7	.64 to .71	3
48 to 55	7	52 to 55	13	2.55 to 3.09	13	.56 to .63	2
40 to 47	7	48 to 51	14	2.00 to 2.54	9	.48 to .55	7
32 to 39	10	44 to 47	15	1.45 to 1.99	9	.40 to .47	9
24 to 31	5	40 to 43	9	.90 to 1.44	12	.32 to .39	11
16 to 23	6	36 to 39	9	.35 to .89	7	.24 to .31	12
8 to 15	4	32 to 35	3	−.20 to .34	14	.16 to .23	13
0 to 7	7	28 to 31	1	−.75 to −.21	7	.08 to .15	11
−8 to −1	3	24 to 27	1	−1.30 to −.76		.00 to .07	10
−16 to −9				−1.85 to −1.31	1	−.08 to −.01	5
−24 to −17	1					−.16 to −.09	3
*Skewness,** g_1	−.05		.33		.47		.72
*Kurtosis,** g_2	1.93		3.09		2.80		3.85

*Based on the moments of the distribution. When a distribution is symmetrical with normal peakedness, $g_1 = 0$ and $g_2 = 3$. When sample size is 89 and the population normal, the 90% confidence limits for population g_1 are −.40 and .40, and for population g_2, 2.33 and 3.80. The 98% limits are −.60 and .60, and 2.16 and 4.44, respectively.

are difficult to deal with statistically. The shape of the distribution is of course an indifferent criterion of the reliability and usefulness of a measure; however, other things equal, a sample distribution which permits definite assumptions about its parent distribution is to be preferred, if only to facilitate statistical analysis.

Residual Measure. Oxtoby (*13*) was apparently the first investigator to attempt to obtain an individual measure of adaptation independent of initial frequency of stuttering. Essentially, her measure is the quotient obtained by dividing the difference between p_1 and p_5, the proportion of words stuttered during the first and fifth readings, respectively, by the expected difference $p_1 - p_5'$, where p_5' is obtained from the equation of the straight line of regression of $p_1 - p_5$ on p_1.

Quarrington (*16*) examined Oxtoby's data and found that they did not satisfy the assumption of homoscedasticity underlying linear regression analysis and further that her measure was positively correlated with initial frequency. He suggested the angular transformation $\phi = 2 \arcsin (p_i)^{1/2}$ where ϕ is twice the angle in radians whose sine is equal to the square root of p_i,

TABLE 3. Equations of regression of ϕ_5 on ϕ_1, coefficients of correlation, and standard errors of estimate in five samples of adaptation data. Sample description includes investigator or place of investigation, number of words in passage read, number of subjects (N), their sex (M, F), age in years (A), mean age (MA), and median age (MedA) to the extent that such information is available.

Sample	*Equation*	r_{12}	$s_{5\cdot1}$
Oxtoby (*14*), 200 words: N = 21M, 3F; A = 16 to 28; MA = 22	$\phi_5' = .886\phi_1 - .169$*	.888	.224
Cohen (*2*), 1 000 words: N = 15M, 5F	$\phi_5' = .953\phi_1 - .183$	.917	.129
Trotter (*20*), 500 words: N = 20; A = 12 to 35	$\phi_5' = .887\phi_1 - .081$	.879	.110
Univ. Iowa, 180 words:† N = 41M, 10F; A = 17 to 25; MedA = 22	$\phi_5' = .775\phi_1 - .064$	.841	.159
Univ. Iowa, 180 words:** N = 74M, 15F; A = 15 to 51; MedA = 22.7	$\phi_5' = .953\phi_1 - .176$	.936	.154

*This equation unexplainably differs from that reported by Quarrington (*16*) for presumably the same data. He reported $\phi_5' = .849\phi_1 - .003$.

†University of Iowa Outpatient Clinic files, 1953 to 1960; the passage 'Arthur the Young Rat' (*8*).

**University of Iowa Speech Clinic files, 1955 to 1959; passage same as above.

the proportion of words stuttered during the *i*th reading.[2]

Quarrington took as the measure of adaptation the difference $\phi_5' - \phi_5$, the ϕ_5' being determined from the equation of the straight line of regression of ϕ_5 on ϕ_1, that is, he took the residuals about the line of regression. When the assumptions of linearity and homoscedasticity in the correlation table are satisfied, such residuals are independent of the other variable. In the present case, $\phi_5' - \phi_5$ is independent of ϕ_1, provided the assumptions are satisfied.

The distributions of the proportions of words stuttered by 89 subjects on the first and fifth readings of the 180-word passage 'Arthur the Young Rat' (*8*) and the distributions of the arc sine transformations of the proportions are shown in Table 1. The subjects were college students enrolled in the University of Iowa Speech Clinic for one

[2]The inverse or arc sine transformation is well known and widely used in sampling problems involving proportions or percentages. The variance of ϕ is, except for extreme proportions, virtually independent of the true proportion; thus the transformation makes the observations of nearly equal precision. Where arrays of proportions are involved, as in the correlation table or variance-analysis classification, the transformation generally improves both the homoscedasticity of data and the shape of the distributions. Eisenhart, Hastay, and Wallis (*4*, chap. 16) include a comprehensive discussion of the origin and nature of the inverse sine transformation.

or more semesters during the period 1955-1959. The males ranged in age from 15 years to 47 years; the females ranged in age from 18 years to 51 years. Although the proportions of words stuttered were somewhat smaller for the females, there was little and insignificant sex difference in adaptation rates. The proportions in Table 1 were observed at the first diagnosis of the subjects. It is believed that the sample is representative of college students who seek admission to campus speech clinics.

Comparison of the distributions of Table 1 brings out the effect of the arc sine transformation. Although the departure from normality remains significant, the improvement in distribution form is sufficient to permit the assumption of linearity and homoscedasticity in the correlation table.

The ϕ_1 and ϕ_5 values from which the distributions in Table 1 were constructed are plotted in Figure 1. The straight line of regression and the second degree curve, both fitted by the method of

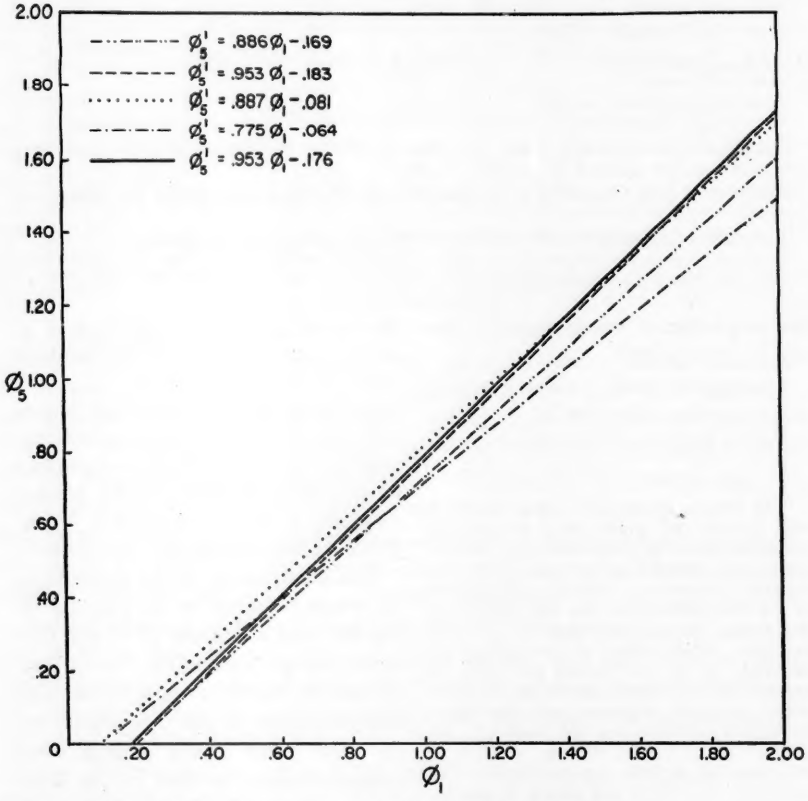

FIGURE 3. Lines of regression of ϕ_5 on ϕ_1 for five samples of stutterers.

least squares, are shown in the figure. The parabola gives a significantly better fit than the straight line, but the reduction from .154 to .146 in the standard deviation of the residuals was too small to be of practical importance, and it was decided to limit discussion to the latter. Although the scatter of the ϕ_5 values about the straight line of regression increases as ϕ_1 increases, the assumption of homoscedasticity is not untenable according to Bartlett's test of homogeneity ($.10 > P > .05$). Despite the departure from normality of the marginal distributions, the distribution of the residuals is nearly normal.

The need for easily computed measures of adaptation independent of initial frequency suggested the conversion of the residuals to standard scores and the construction of the chart in Figure 2. The scores in the chart are standard scores obtained from

$$A\phi = -10\,(\phi_5 - \phi_5')/\,s_{5\cdot1} + 50$$

where ϕ_5' is the expected value given by the regression equation and $s_{5\cdot1}$ is the standard error of estimate, that is, the standard deviation of the residuals. The negative sign is necessary to make the scores vary directly with adaptation, since negative residuals correspond to adaptation scores greater than expectation.

The chart is easily used. If a subject stutters on 20 words in reading a 180-word passage the first time and on 15 words the fifth time, the proportions of stuttered words are $p_1 = .111$ and $p_5 = .083$. The score in the chart corresponding to these proportions is 43. As a rule, the chart gives scores within ± 1 of their computed values. In the above illustration, for example, the transformed values of the proportions, as given by Table 4, are .679 and .584, respectively. When .679 is substituted in the linear regression equation of Figure 1, ϕ_5' turns out to be .471. Hence, $A\phi = -10\ (.584 - .471)\ /\ .154 + 50$ or 43. The distribution of the $A\phi$ scores in the sample of 89 is shown in the second column of Table 2.

The equations of the regression of ϕ_5 on ϕ_1 and related statistics for five samples are shown in Table 3, and the regression lines are plotted in Figure 3. The regression lines are not very different, and a test of the hypothesis that the true or population regressions coincide is entirely tenable, the ratio of the variance of residuals among samples to the variance of residuals within samples being 1.15 with 8 and 194 *df*. However, the residual variances within samples are significantly different at the .025 level, according to the Bartlett test. Apart from the question of whether the heterogeneity is sufficient to invalidate the variance-ratio test of coincidence of true regression lines, it is sufficient to raise doubt about general use of the chart of standard scores if accurate results are desired. Actually, the chart gives exact adaptation scores independent of initial frequency of stuttering for only the 89 subjects in the sample at the time of observation. However, if the regression line for a given sample is approximately coincident with or parallel to that of the sample of 89, the chart will give scores very highly correlated with the scores computed from the residuals about the regression line in the given sample—perfectly correlated if coin-

cidence or parallelism of regression lines exists, since differences in scatter about the lines of regression will affect the scores by constant amounts. It would seem that the chart may fulfill in part Quarrington's (*16*) expectation of adaptation norms. At any rate, the adaptation scores of the chart should prove useful as reference data. The sample of 89 is an unusually large sample of stutterers.

The residual measures of adaptation have several advantages. They are statistically independent of initial frequency of stuttering. They can be expected to be distributed in approximately normal form and to be easily convertible to meaningful standard scores. They are relatively difficult to compute if the residuals about the regression line for the sample in hand are desired, but it is likely that the chart of Figure 2 will give scores accurate enough for many purposes. When this is the case, they are extremely easy to compute.

They also have several limitations. They do not permit an easy, straightforward test of the hypothesis that a particular subject's true adaptation score is zero. Where there have been more than two readings, as is usually the case, they do not make use of all of the information available. They are computed on the assumption that the residuals are sufficiently homoscedastic over the range of ϕ_1 to justify use of a single standard error of estimate. The assumption was not clearly tenable in the sample of 89 and it may generally be in doubt. Where there is heterogeneity of residuals in the population, adaptation is not equally predictable for all values of initial frequency of stuttering and adaptation scores not entirely comparable.

Normal Deviate Measure. The residual method of measuring adaptation defines the expected adaptation score in terms of the regression of final frequency of stuttering on initial frequency in a given sample. It is possible to derive a measure of adaptation without reference to the group, a measure which may be immediately tested for significant departure from zero.

The measure is obtained by treating the proportion of stuttered words on the first and, say, fifth reading as related sample proportions and testing the difference between them for significance. The stuttered and nonstuttered words of a given subject on the first and fifth readings of a passage may be classified in the 2 x 2 table

		Fifth Reading	
		Nonstuttered	Stuttered
First Reading	Stuttered	*A*	*B*
	Nonstuttered	*C*	*D*

where *A*, *B*, *C*, and *D* are the frequencies of stuttered and nonstuttered words, as classified. It is to be noted that the sum of *A*, *B*, *C*, and *D* is equal to the number of words, *N*, in the passage, and that, since the proportions of

words stuttered on the two readings are $(A + B) / N$ and $(B + D) / N$, the difference between proportions is $(A - D) / N$.

McNemar (*11*) has shown[3] that, under the null hypothesis, the frequencies of A (or D) follow the binomial model $(\frac{1}{2} + \frac{1}{2})^{A+D}$. The normal approximation to the binomial, adjusted for discontinuity, reduces to $z = (|A - D| - 1)/\sqrt{A + D}$ in which z is a normal deviate.[4] As such, it may be used to test the null hypothesis that there is no difference between the true proportions against the alternative that the proportion of words stuttered on the fifth reading is less than the proportion stuttered on the first. When $z \geqslant .84$, the null hypothesis is discredited at the 20% level; when $z \geqslant 1.28$, the null hypothesis is discredited at the 10% level; when $z \geqslant 1.64$, the null hypothesis is discredited at the 5% level; and so on.

Moreover, z may be taken as an adaptation score A_z. When the adjustment for discontinuity is made, normal areas correspond closely to the binomial probabilities (see Footnote 4). If the original sign of the difference $A - D$ is returned to after the adjustment is made, A_z may be thought of as a standard score in a normal distribution. An ambiguity will be encountered when $|A - D| = 1$, $|A - D| = 0$, or $|A - D| = 2$. Since the adjustment for discontinuity is made by subtracting 1 from the absolute difference, two subjects having the same $(A + D)$ value but differing by 1 or 2 in values of A may get the same score. However, such subjects will be showing zero or very slight adaptation, and little information will be lost if they are assigned scores of zero.

The A_z scores are not difficult to compute. Suppose that a subject stuttered 20 times during the first reading of a 180-word passage and 12 times during the fifth reading, five of the stuttered words being common to both readings. Since $A + B = 20$, $B + D = 12$, and $B = 5$, A must equal 15 and D, 7. Hence, $A_z = (15 - 7 - 1)/\sqrt{15 + 7} = 1.49$. Thus, for this subject the adaptation score is 1.49, significantly different from zero at the 10% level.

[3] Tate and Clelland (*19*, pp. 98-100) discuss applications and give tables of critical values of $A - D$ for the two-sample related proportions test. Cochran (*1*) has extended the method to three or more related sample proportions. The extension makes possible a test of differences in proportions of stuttered words over all readings. However, the test would be extremely laborious where the number of words in the passage is large and would not lead to a meaningful adaptation score. If the reader is interested in exploring the possibilities of a test of differences among the five proportions, he is referred to Tate and Clelland (*19*, pp. 106-108) for applications of Cochran's test.

[4] It may come as a surprise to the reader to find no restriction placed on the size of $A + D$. The usual restriction, in justifying the use of the normal approximation to the binomial, is that the sample must be of sufficient size to make the expected frequency at least 5. The restriction applied to the binomial $(\frac{1}{2} + \frac{1}{2})^{A+D}$ would mean that $A + D$ must not be less than 10. However, the restriction may be relaxed here where precise results are not needed. Consider the case $A + D = 2$, so that the binomial is $(\frac{1}{2} + \frac{1}{2})^2$. The exact binomial probabilities of 2, 1, and 0 As (or Ds) are .25, .50, and .25, respectively. The probabilities obtained from the normal approximation are .22, .52, and .22. In general, when $A + D$ is greater than 2, the difference between the binomial and normal probabilities is not greater than .01.

TABLE 4. Transformation of a proportion p to radians ϕ where $\phi = 2 \text{ arc sin } \sqrt{p}$. (This table was adapted by Richard I. Lanyon from Table 16.8 of George W. Snedecor's *Statistical Methods*, 4th ed., published by Iowa State University Press, Ames, and is used with permission of the author and publisher.)

p	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
.00	.0000	.0632	.0894	.1096	.1267	.1414	.1550	.1675	.1791	.1899
.01	.2004	.2101	.2196	.2286	.2374	.2457	.2538	.2614	.2691	.2765
.02	.2838	.2908	.2977	.3044	.3110	.3176	.3239	.3302	.3361	.3424
.03	.3484	.3539	.3599	.3655	.3711	.3763	.3819	.3871	.3923	.3978
.04	.4028	.4077	.4129	.4178	.4227	.4276	.4325	.4370	.4419	.4464
.05	.4510	.4555	.4601	.4646	.4691	.4733	.4778	.4821	.4866	.4908
.06	.4950	.4992	.5033	.5075	.5114	.5156	.5198	.5236	.5278	.5316
.07	.5355	.5393	.5431	.5473	.5512	.5547	.5585	.5623	.5662	.5697
.08	.5735	.5773	.5808	.5843	.5882	.5917	.5951	.5990	.6025	.6060
.09	.6095	.6129	.6164	.6199	.6231	.6266	.6301	.6335	.6366	.6402
.10	.6437	.6468	.6503	.6534	.6566	.6601	.6632	.6664	.6698	.6730
.11	.6761	.6793	.6824	.6856	.6887	.6918	.6950	.6981	.7013	.7044
.12	.7075	.7107	.7135	.7166	.7198	.7226	.7257	.7288	.7316	.7348
.13	.7376	.7407	.7435	.7466	.7494	.7526	.7554	.7582	.7613	.7641
.14	.7669	.7700	.7728	.7756	.7784	.7812	.7840	.7871	.7899	.7927
.15	.7955	.7983	.8011	.8039	.8067	.8095	.8119	.8147	.8175	.8203
.16	.8231	.8259	.8283	.8311	.8339	.8367	.8391	.8419	.8447	.8472
.17	.8500	.8528	.8552	.8580	.8604	.8632	.8657	.8685	.8709	.8737
.18	.8761	.8789	.8814	.8842	.8866	.8894	.8918	.8943	.8971	.8995
.19	.9020	.9048	.9072	.9097	.9121	.9149	.9173	.9198	.9222	.9247
.20	.9271	.9299	.9323	.9348	.9372	.9397	.9421	.9446	.9470	.9494
.21	.9522	.9547	.9571	.9596	.9620	.9645	.9665	.9690	.9714	.9739
.22	.9763	.9788	.9812	.9837	.9861	.9885	.9906	.9931	.9955	.9980
.23	1.000	1.003	1.005	1.007	1.010	1.012	1.014	1.017	1.019	1.022
.24	1.024	1.026	1.029	1.031	1.033	1.036	1.038	1.040	1.043	1.045
.25	1.047	1.050	1.052	1.054	1.056	1.059	1.061	1.063	1.066	1.068
.26	1.070	1.072	1.075	1.077	1.079	1.081	1.084	1.086	1.088	1.090
.27	1.093	1.095	1.097	1.100	1.102	1.104	1.106	1.109	1.111	1.113
.28	1.115	1.117	1.120	1.122	1.124	1.126	1.129	1.131	1.133	1.135
.29	1.137	1.140	1.142	1.144	1.146	1.148	1.151	1.153	1.155	1.157
.30	1.159	1.161	1.164	1.166	1.168	1.170	1.172	1.175	1.177	1.179
.31	1.181	1.183	1.185	1.188	1.190	1.192	1.194	1.196	1.198	1.200
.32	1.203	1.205	1.207	1.209	1.211	1.213	1.215	1.218	1.220	1.222
.33	1.224	1.226	1.228	1.230	1.232	1.235	1.237	1.239	1.241	1.243
.34	1.245	1.247	1.249	1.251	1.253	1.256	1.258	1.260	1.262	1.264

(Continued on following page.)

TABLE 4. Transformation of a proportion p to radians ϕ where $\phi = 2 \arcsin \sqrt{p}$. (Continued from preceding page.)

p	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
.35	1.266	1.268	1.270	1.272	1.274	1.277	1.279	1.281	1.283	1.285
.36	1.287	1.289	1.291	1.293	1.295	1.297	1.300	1.302	1.304	1.306
.37	1.308	1.310	1.312	1.314	1.316	1.318	1.320	1.322	1.324	1.326
.38	1.329	1.331	1.332	1.334	1.337	1.339	1.341	1.343	1.345	1.347
.39	1.349	1.351	1.353	1.355	1.357	1.359	1.361	1.363	1.365	1.367
.40	1.369	1.371	1.374	1.376	1.378	1.380	1.382	1.384	1.386	1.388
.41	1.390	1.392	1.394	1.396	1.398	1.400	1.402	1.404	1.406	1.408
.42	1.410	1.412	1.414	1.416	1.418	1.420	1.422	1.424	1.426	1.428
.43	1.430	1.432	1.434	1.436	1.438	1.440	1.442	1.444	1.446	1.448
.44	1.450	1.452	1.454	1.456	1.458	1.460	1.462	1.464	1.466	1.468
.45	1.471	1.473	1.475	1.477	1.479	1.481	1.483	1.485	1.487	1.489
.46	1.491	1.493	1.495	1.497	1.499	1.501	1.503	1.505	1.507	1.509
.47	1.511	1.513	1.515	1.517	1.519	1.521	1.523	1.525	1.527	1.529
.48	1.531	1.533	1.535	1.537	1.539	1.541	1.543	1.545	1.547	1.549
.49	1.551	1.553	1.555	1.557	1.559	1.561	1.563	1.565	1.567	1.569
.50	1.571	1.573	1.575	1.577	1.579	1.581	1.583	1.585	1.587	1.589
.51	1.591	1.593	1.595	1.597	1.599	1.601	1.603	1.605	1.607	1.609
.52	1.611	1.613	1.615	1.617	1.619	1.621	1.623	1.625	1.627	1.629
.53	1.631	1.633	1.635	1.637	1.639	1.641	1.643	1.645	1.647	1.649
.54	1.651	1.653	1.655	1.657	1.659	1.661	1.663	1.665	1.667	1.669
.55	1.671	1.673	1.675	1.677	1.679	1.681	1.683	1.685	1.687	1.689
.56	1.691	1.693	1.695	1.697	1.699	1.701	1.703	1.705	1.707	1.709
.57	1.711	1.713	1.715	1.717	1.719	1.721	1.723	1.725	1.727	1.729
.58	1.731	1.733	1.736	1.738	1.740	1.742	1.744	1.746	1.748	1.750
.59	1.752	1.754	1.756	1.758	1.760	1.762	1.764	1.766	1.768	1.770
.60	1.772	1.774	1.776	1.778	1.780	1.782	1.784	1.786	1.789	1.791
.61	1.793	1.795	1.797	1.799	1.801	1.803	1.805	1.807	1.809	1.811
.62	1.813	1.815	1.817	1.819	1.821	1.823	1.826	1.828	1.830	1.832
.63	1.834	1.836	1.838	1.840	1.842	1.844	1.846	1.848	1.850	1.852
.64	1.855	1.857	1.859	1.861	1.863	1.865	1.867	1.869	1.871	1.873
.65	1.875	1.878	1.880	1.882	1.884	1.886	1.888	1.890	1.892	1.894
.66	1.896	1.899	1.901	1.903	1.905	1.907	1.909	1.911	1.914	1.916
.67	1.918	1.920	1.922	1.924	1.926	1.928	1.930	1.933	1.935	1.937
.68	1.939	1.941	1.943	1.945	1.948	1.950	1.952	1.954	1.956	1.959
.69	1.961	1.963	1.965	1.967	1.969	1.971	1.974	1.976	1.978	1.980

(Continued on following page.)

TABLE 4. Transformation of a proportion p to radians ϕ where $\phi = 2$ arc sin $\sqrt{p}$. (Continued from preceding page.)

p	0	1	2	3	4	5	6	7	8	9
.70	1.982	1.984	1.987	1.989	1.991	1.993	1.996	1.998	2.000	2.002
.71	2.004	2.006	2.008	2.011	2.013	2.015	2.018	2.020	2.022	2.024
.72	2.026	2.029	2.031	2.033	2.035	2.037	2.040	2.042	2.044	2.047
.73	2.049	2.051	2.053	2.056	2.058	2.060	2.062	2.065	2.067	2.069
.74	2.071	2.074	2.076	2.078	2.080	2.083	2.085	2.087	2.090	2.092
.75	2.094	2.097	2.099	2.101	2.104	2.106	2.108	2.111	2.113	2.115
.76	2.118	2.120	2.122	2.125	2.127	2.129	2.132	2.134	2.137	2.139
.77	2.141	2.144	2.146	2.148	2.151	2.153	2.155	2.158	2.160	2.163
.78	2.165	2.168	2.170	2.173	2.175	2.177	2.180	2.182	2.184	2.187
.79	2.189	2.192	2.194	2.197	2.199	2.202	2.204	2.207	2.209	2.211
.80	2.214	2.217	2.219	2.222	2.224	2.227	2.229	2.232	2.234	2.237
.81	2.240	2.242	2.244	2.247	2.250	2.252	2.255	2.257	2.260	2.263
.82	2.265	2.268	2.271	2.273	2.276	2.278	2.281	2.284	2.286	2.289
.83	2.292	2.294	2.297	2.300	2.302	2.305	2.308	2.310	2.313	2.316
.84	2.318	2.321	2.324	2.327	2.330	2.332	2.335	2.338	2.340	2.343
.85	2.346	2.349	2.352	2.354	2.357	2.360	2.363	2.366	2.369	2.372
.86	2.375	2.377	2.380	2.383	2.386	2.389	2.392	2.395	2.398	2.401
.87	2.404	2.407	2.410	2.413	2.416	2.419	2.422	2.425	2.428	2.431
.88	2.434	2.437	2.440	2.443	2.447	2.450	2.453	2.456	2.459	2.462
.89	2.465	2.469	2.472	2.475	2.478	2.481	2.485	2.488	2.491	2.495
.90	2.498	2.501	2.505	2.508	2.511	2.515	2.518	2.522	2.525	2.529
.91	2.532	2.536	2.539	2.543	2.546	2.550	2.553	2.557	2.561	2.564
.92	2.568	2.572	2.575	2.579	2.583	2.587	2.590	2.594	2.598	2.602
.93	2.606	2.610	2.614	2.618	2.622	2.626	2.630	2.634	2.638	2.642
.94	2.646	2.651	2.655	2.659	2.664	2.668	2.672	2.677	2.681	2.686
.95	2.691	2.696	2.700	2.705	2.709	2.714	2.719	2.724	2.729	2.734
.96	2.739	2.744	2.749	2.754	2.760	2.765	2.770	2.776	2.782	2.788
.97	2.793	2.799	2.805	2.811	2.818	2.824	2.831	2.837	2.844	2.851
.98	2.858	2.865	2.872	2.880	2.888	2.896	2.904	2.913	2.922	2.931
.99	2.941	2.952	2.962	2.974	2.987	3.000	3.015	3.032	3.052	3.078
1.00	3.142									

It will be seen that this measure of adaptation is directly affected by consistency in stuttering, that is, the extent to which the subject stutters on the same words in the first and fifth readings. If, for example, in the above illustration the stuttered words common to both readings had been 10 instead of 5, A_z would have been $(10 - 2 - 1) / \sqrt{10 + 2}$ or 2.02 instead of 1.49. The increase in z reflects a stronger demonstration of adaptation in view of greater

consistency. This seems to make sense, since adaptation and consistency are antagonistic.[5]

The A_z or normal deviate measure of adaptation appears to be sound. It rests on a minimum of assumptions. It permits an immediate test of the hypothesis that a particular subject's true adaptation is zero and thus permits logical elimination from study the subjects who fail to adapt significantly. Its chief limitations are failure to make use of all of the information available, in case a subject has read a passage more than twice, and ambiguity of scores when A and D differ by 2 or less. The latter does not seem serious in practical work.

The distribution of the A_z scores of the 89 subjects previously referred to is shown in the third column of Table 2.

Trend Measure. The $A\phi$ and A_z measures of adaptation discussed above are obtained through comparison of frequency of stuttering on the first reading with that on the fifth. (Of course, the second, third, or fourth reading might be used instead of the fifth.) If adaptation is defined as change in the frequency of stuttering from one reading to any subsequent reading, and if a subject reads a passage more than two times, these measures obviously do not make use of all of the information available. When a subject reads a passage five times, there are 10 possible comparisons of frequency of stuttering on a given reading with that on a subsequent reading. One way to use all of the information would be to obtain scores from the 10 comparisons and average them. Suppose, for example, that the proportions of stuttered words for a given subject are $p_1 = .30$, $p_2 = .24$, $p_3 = .28$, $p_4 = .16$, $p_5 = .20$. The 10 pairs of proportions $p_i p_j$ $(i < j)$, referred to the chart of Figure 2, yield the scores 44, 38, 58, 31, 49, 42, 54, 48, and 29, whose mean is about 44.

The normal deviate method might be applied in the same way, but with considerably more difficulty, since it would be necessary to count the number of stuttered words common to each pair of readings.

Whatever practical advantages measures of adaptation based on comparisons by pairs might have, however, would be nullified by the statistical complications arising in analysing non-independent scores. It would be extremely difficult to devise a satisfactory test of the hypothesis that such scores, for given individuals, indicated significant amounts of adaptation.

If adaptation is defined in terms of trend of frequency of stuttered words from the first through the fifth reading, a measure of statistical purity may be obtained by finding the slope of the trend line. Given the five readings, proportions of stuttered words, and arc sine values of the proportions, as read from Table 4,

Reading, R	Proportion of Stuttered Words, p	Arc Sine Transformation of p, ϕ
1	.30	1.16
2	.24	1.02
3	.28	1.12
4	.16	.82
5	.20	.93

[5] When consistency is defined as the ratio $\frac{0k_1 + 40k_2 + 60k_3 + 80k_4 + 100k_5}{100\,(k_1 + k_2 + k_3 + k_4 + k_5)}$, where k_i indicates the number of words stuttered i times ($i = 1, 2, 3, 4, 5$), the coefficients of correlation of A_p, $A\phi$, and A_z with consistency were $-.584$, .260, and .119, respectively, in the sample of 89.

there are various ways of fitting a line to the R,p or R,ϕ values. Since the arc sine transformation makes the proportions of nearly equal precision, it is preferable to fit the line to the R,ϕ values. The five pairs of values, (1, 1.16), (2, 1.02), (3, 1.12), (4, .82), (5, .93), might be plotted, a line fitted by inspection, and the slope of the line determined from the graph. At the other extreme, a parabola might be fitted by the method of least squares, and an average taken of the slopes of the lines tangent to the parabola at various values of R.

A method more exact than the first, less laborious than the second, and consistent with the accuracy of adaptation data, is to work with the first two pairs and last two pairs of values and estimate the slope b by the formula,

$$b = \frac{\frac{1}{2}(\phi_1 + \phi_2) - \frac{1}{2}(\phi_4 + \phi_5)}{\frac{1}{2}(R_1 + R_2) - \frac{1}{2}(R_4 + R_5)}.$$

For the given data,

$$b = \frac{\frac{1}{2}(1.16 + 1.02) - \frac{1}{2}(.82 + .93)}{\frac{1}{2}(1 + 2) - \frac{1}{2}(4 + 5)} = -.072.$$

Since the denominator in the formula, given five readings, will be the constant -3, and since there is no advantage in multiplying by $\frac{1}{2}$, a trend measure of adaptation A_t may be defined as

$$A_t = \phi_1 + \phi_2 - \phi_4 - \phi_5.$$

If there is need to return to the actual slope, one needs merely to divide A_t by -6. For the given data,

$$A_t = 1.16 + 1.02 - .82 - .93 = .43.$$

Whether the adaptation is significant may be determined by the trend test (see Footnote 1). In the above illustration, the ranks of the proportions are 5, 3, 4, 1, 2. The sum of squares of the deviations of the ranks from the 5, 4, 3, 2, 1 order is 4. This is significant at the 7% level.

The distribution of the A_t scores for the 89 subjects previously mentioned is shown in the fourth column of Table 2.

The trend measure is perhaps as useful as any which could be feasibly derived when it is desired to consider adaptation over five readings. It should compare favorably with the measure obtained from the slope of the least-squares straight line or from the average slope of the least-squares second degree curve; in fact, it should show nearly perfect correlation with the first of these. Since it makes use of four-fifths of the information, it should be more reliable than the percentage, residual, and normal deviate measures. It is not difficult to apply and is easily tested for significance. Finally, it leads naturally to a simple measure of individual variability in adaptation.

Two individuals may have identical or parallel trend lines and identical A_t scores, but show marked differences in the manner in which their ϕ_t are scattered about the lines. The question of whether differences in variation about trend lines are related to important individual differences in stuttering behavior invites investigation. As the measure of variability, the sum of the absolute deviations of the ϕ_t from trend line may be used. This sum $\Sigma|d_t|$ may be obtained by plotting the ϕ_t and the line and measuring the vertical deviations of the ϕ_t from the line. It may be more easily and accurately obtained from the equation,

$\Sigma d_i = | \phi_1 - \phi_2 - A_t/6 | + | \phi_4 - \phi_5 - A_t/6 | + | \phi_3 - (\phi_1 + \phi_2 + \phi_4 + \phi_5) /4|$.

For the given data,

$\Sigma d_i = | 1.16 - 1.02 - .43/6 | + | .82 - .93 - .43/6 | + | 1.12 - (1.16 + 1.02 + .82 + .93) / 4 | = .07 + .18 + .14 = .39$.

If it is desired to describe variability in terms of the average or mean deviation, the quantity Σd_i must be divided by 5.

Comparisons of Measures

The distributions of the percentage, residual, normal deviate, and trend adaptation scores for the previously described 89 subjects are shown in Table 2. The moment measures of skewness and kurtosis are shown at the foot of the table. The $A\phi$ distribution is entirely consistent, and the A_z distribution not inconsistent, with the assumption of population normality. The A_p and A_t distributions are inconsistent with the assumption, the former indicating departure from normal peakedness, the latter departure from symmetry. Parametric statistical analyses of the A_p and A_t scores would be of doubtful propriety, particularly in small samples.

TABLE 5. Intercorrelation coefficients of four measures of adaptation and initial frequency of stuttering for 89 subjects.

Measure	$A\phi$	A_z	A_t	p_i
Percentage (A_p)	.736	.378	.496	−.505
Residual ($A\phi$)		.856	.855	−.032
Normal Deviate (A_z)			.820	.305
Trend (A_t)				.167
Initial Proportion Stuttered Words (p_i)				

The intercorrelation of the measures and their correlation with initial frequency are summarized in Table 5. To simplify discussion, the subscripts of the symbols in the table will be used as subscripts for the corresponding coefficients of correlation. Thus, r_{pi} will designate the coefficient of correlation of the percentage measure with initial frequency of stuttering.

Of the coefficients of correlation of the four measures of adaptation with initial frequency, r_{pi} is significantly different from zero at the 0.1% level, and r_{zi} is significantly different from zero at the 5% level. All of the six intercorrelation coefficients among the measures of adaptation are significantly different from zero at the 0.1% level. Application of Hotelling's test[6] for differences between the latter coefficients, taken two at a time, indicate that, of the 12 differences to which the test is applicable, only the three differences, $r\phi_z - r\phi_t$, $r\phi_z - r_{zt}$, and $r\phi_t - r_{zt}$, are not significant at the 5% level or lower.

The $A\phi$, A_z, and A_t measures are significantly better correlated with each other than with A_p. This fact combined with A_p's significant and relatively strong correlation with initial frequency of stuttering and its statistical limitations, pointed out in earlier paragraphs, indicates that it is an unsatisfactory measure of adaptation.

[6]The Hotelling test (7) for differences between correlation coefficients in the same sample requires that the coefficients to be compared involve a common variable. Hence, the test is not applicable to the differences $r_{p\phi} - r_{zt}$, $r_{pz} - r\phi_t$, and $r_{pi} - r\phi_z$. The latter two differences are highly significant according to the independent sample test, a test which ordinarily gives conservative results in the related sample situation.

In the absence of empirical information, only tentative and more or less speculative statements about the relative merits of the $A\phi$, A_z, and A_t measures are possible. Each of the three has a rational basis and each has advantages and disadvantages. Both their definitions and their intercorrelation indicate that each takes into account certain features of adaptation not taken into account by the others and summarizes individual adaptation in somewhat different ways.

$A\phi$ is the easiest to compute, provided the subjects can be considered members of the population represented by the sample of 89 or essentially like the members of that population. In that case, the use of the chart of standard scores is justified. If the chart is not used, $A\phi$ is the most difficult to compute. It does not provide a satisfactory test of the significance of a subject's adaptation score; however, where there is doubt, the test for differences between related proportions (see Footnote 3) could be used to eliminate subjects whose adaptation is not significant. The $A\phi$ scores will be generally tractable in statistical analysis. Their independence of initial frequency should make $A\phi$ particularly appropriate in studies of the relation of adaptation to severity of stuttering and to other variables which may be related to initial frequency.

A_z is more easily and satisfactorily tested for significance than the other two. It is the only measure which directly takes into account consistency of stuttering. When adaptation apart from questions of consistency is of interest, A_z would not ordinarily be used, except possibly in testing for significance of individual adaptation. On the other hand, where adaptation within the limits set by consistency is of interest, A_z should prove more useful than either $A\phi$ or A_t. Whether or not it is used to provide an adaptation score, A_z provides a relatively powerful test of the significance of a given subject's adaptation.

A_t should be useful in describing the adaptation of a group over four or five readings. It has the further advantage of leading to a measure of individual variability in adaptation. Although, with modifications, it could be applied to two or three readings, it would seem poorer than either $A\phi$ or A_z in cases of fewer than four readings. It should prove particularly useful in studies of trend and variation in individual adaptation.

Regarding the reliability of the three measures, A_t uses twice as much information as the other two and should turn out to be the most reliable. The ambiguity of A_z in situations discussed earlier and A_z's significant correlation with initial frequency of stuttering suggest that it will prove to be the least reliable.

Summary

The purposes of this paper were to examine several measures of adaptation and to present aids to their computation. The experimental data consisted mainly of the number of words stuttered on each of five successive readings of a 180-word passage by each of 89 stutterers. The distributions and intercorrelations of four measures of adaptation—designated the percentage, residual, normal deviate, and trend measures—in the sample of 89 were compared.

Each of the four measures appeared to have certain advantages and disadvantages. The percentage measure seems to be the least satisfactory. The choice among the other three measures depends in part on the purpose for which they will be used. Both their definitions and intercorrelation indicate that each takes into account certain features of adaptation not taken into account by the others and summarizes individual adaptation in a somewhat different way.

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Vein Plug Stapedioplasty and Bone Conduction Acuity

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Present day surgical management of otosclerosis dates to the rather recent perfection of the fenestration operation. As described by Lempert (*6*), this procedure bypasses the diseased oval window area and opens a new window at the horizontal semicircular canal. With optimum results, fenestration surgery will restore the air conduction threshold to within 20 to 25 db of normal. The residual loss that persists after surgery is caused by the permanent interruption of the ossicular chain that occurs as a necessary step in the procedure.

Since clinical otosclerosis is essentially a conductive impairment it was assumed earlier that preoperative bone conduction measurements provided a reliable estimate of the true potential of the cochlea. No shift in the bone conduction level following surgery was expected. However, in 1948 Woods (*11*) reported a mean bone conduction improvement of 11.4 db for the speech frequencies after fenestration. Juers (*3*) reported a gain in bone conduction responses ranging from approximately 1 db for 250 cps to 13 db for 2 000 cps. Other postoperative reports indicated similar favorable shifts in bone conduction threshold (*2*, 7).

Several hypotheses have been advanced to account for this auditory pattern. Shambaugh and Carhart (*9*), comparing pre- and postoperative bone conduction tests on hundreds of patients before and after fenestration, found that the gain in bone conduction acuity consisted on the average of 6 db at 500 cps, 10 db at 1 000 cps, 15 db at 2 000 cps, and 5 db at 4 000 cps. In attempting to explain these shifts these authors reasoned that fixation of the stapes modifies the mechanical constants of the inner ear. According to Shambaugh and Carhart, improved bone conduction measurements following fenestration are caused by a removal of a conductive block rather than by a correction of inner ear pathology. While the cochlear reserve concealed by 'mechanical factors' is small compared to the air conduction impairment, it is a valuable potential that

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cannot be overlooked. Thus, it was suggested that in prefenestration audiometry the audiologist frequently may correct the bone conductive measurements by an amount approximating the error introduced by the 'Carhart notch.'

Because of the sizeable gap between air and bone thresholds that persisted following fenestration, another procedure in otosclerosis surgery was introduced in 1953. Instead of providing a pathway for sound at the horizontal semicircular canal, an effort was made to re-establish the normal route of sound through the ossicular chain. Following an early technique that was revived by Rosen (*8*), otologists mobilized the stapes, freeing it from the otospongiotic and otosclerotic growth which had caused its fixation. Since the mobilization procedure leaves the ossicular chain and footplate intact, complete elimination of the conductive loss became the surgical goal. However, stapes mobilization did not produce consistently satisfying and lasting results since reankylosis frequently occurred (*4*). The search for improved approaches in otosclerosis surgery continued.

A more recent milestone in otosclerosis surgery was reached in 1955 when Shea (*10*) described a method of stapes replacement. This procedure removes the entire stapes and substitutes a prosthesis that creates a link between the oval window and the remainder of the ossicular chain. This link constitutes a *stapedioarthroplasty* which permits appropriate middle ear function.

Keen interest in bone conduction thresholds accompanied the growth of stapes replacement surgery. Attacking the footplate directly and removing the stapes is a microscopic procedure. There is the constant danger of instrument penetration into the vestibule, threatening destruction of vital sections which are only one to two millimeters removed from the oval window (*1*). Further, removing the stapes frequently requires aggressive manipulation of the ossicular chain. The possibility of cochlear damage not unlike acoustic trauma is introduced. A decrease in bone conduction acuity following surgery would appear if either of these adverse events occurred.

The purpose of the present study is to investigate the influence of one type of stapes replacement surgery on bone conduction threshold. Specific questions asked are: What is the effect of vein plug stapedioplasty upon bone conduction acuity? Are the norms predicting bone conduction shifts following fenestration appropriate to this particular stapes procedure?

Procedure

Between May and November, 1959, 100 consecutive stapes replacements were accomplished. The subjects were 40 males and 60 females. The average age was 42. A technique known as vein plug stapedioplasty[1] was employed (*5*). A section of vein 4 mm long and approximately 2 to 2.5 mm in diameter is taken from the back of the hand and secured by a simple knot to a length of 5-0 gauge stainless steel suture wire measuring 4.5 mm. The resulting vein plug prosthesis is inserted into the exposed oval window niche with the

[1]This technique was developed by C. M. Kos, M.D., the surgeon for all cases reported in this study.

TABLE 1. Mean preoperative and six-weeks postoperative air conduction thresholds in db for 100 consecutive vein plug stapedioplasty operations.

Measure	*Frequency in cps*			
	500	*1 000*	*2 000*	*4 000*
Preoperative	46.0	48.9	47.9	54.4
Postoperative (Six Weeks)	7.8	11.4	18.1	38.1
Gain in db	38.2	37.5	29.8	16.3

distal end of the wire looped over the long process of the incus and crimped firmly in place.

Pre- and postoperative air and bone conduction pure tone threshold measurements were completed by staff audiometrists in the Audiology Section, Department of Otolaryngology and Maxillofacial Surgery, University Hospitals, University of Iowa.

Results and Discussion

Closure of Air-Bone Gap. The first consideration was to determine the over-all success rate of the procedure described above. Since a marked difference between the preoperative bone conduction and air conduction thresholds is the classical otosclerotic pattern it seems reasonable that removal of this gap be accepted as the criterion for success. In order to allow for testing variability, it was agreed that closure of this gap between air and bone thresholds is achieved when the postoperative air conduction threshold for the speech frequencies shifts to within 10 db or less of the preoperative bone conduction level. Based upon the preoperative and six-weeks postoperative measurements the 100 operations reported here produced the success rate of 90 gap closures. The combined mean air conduction shift for 500, 1 000, 2 000, and 4 000 cps was 30.5 db. Reported in Table 1 are the mean preoperative and six-weeks postoperative air conduction thresholds for each of the four test frequencies.

Bone-Conduction Threshold Shifts. The next step was to investigate data related specifically to the problem of this study. How had the surgical procedure influenced bone conduction thresholds? In order to observe the continuing influence of vein plug stapedioplasty on bone conduction acuity two postoperative check points were selected. The six- and 18-weeks postoperative measurements were compared to preoperative thresholds. A summary of these data appears in Table 2.

TABLE 2. Mean preoperative and six- and 18-weeks postoperative bone conduction thresholds in db for 100 consecutive vein plug stapedioplasty operations.

Test Time	*Frequency in cps*			
	500	*1 000*	*2 000*	*4 000*
Preoperative	00.0	13.2	19.0	19.3
Postoperative (Six Weeks)	01.9	8.7	15.9	26.1
Postoperative (18 Weeks)	02.4	8.3	15.1	23.2

TABLE 3. Analysis of variance of preoperative and six- and 18-weeks postoperative bone conduction tests at 500, 1 000, 2 000, and 4 000 cps.

Source of Variation	*df*	*ms*	*F*	*P*
Pure Tone Frequency (F)	3	25 233.02	116.54	1%
Time of Test (T)	2	85.68	.31	NS
Subjects (S)	99	803.18		
F x T	6	809.68	15.85	1%
F x S	297	216.50		
T x S	198	273.52		
F x T x S	594	51.08		
Total	1 199			

An analysis of variance, reported in Table 3, indicates that the interaction of frequency with time of test is significant: that is, the differences in hearing acuity among three test times vary from one frequency to another. In order to investigate the specific nature of this interaction, *F* ratios for evaluation of differences among test times were obtained for each of the four pure tone frequencies. Summaries of analyses of variance, reported in Table 4, indicate that no significant threshold shifts occurred at 500 cps, while the 1 000 cps, 2 000 cps, and 4 000 cps shifts occurring from one test time to another were significant.

TABLE 4. Summaries of analyses of variance testing differences in the preoperative, postoperative at six weeks, and postoperative at 18 weeks thresholds of four pure tone frequencies.

Source	*df*	*ms*	*F*	*P*
500 cps				
Time of Test (T)	2	160.33	1.25	NS
Subjects (S)	99	243.92		
T x S	198	128.26		
Total	299			
1 000 cps				
Time of Test (T)	2	756.03	6.82	1%
Subjects (S)	99	270.93		
T x S	198	110.85		
Total	299			
2 000 cps				
Time of Test (T)	2	432.25	5.42	1%
Subjects (S)	99	331.98		
T x S	198	79.75		
Total	299			
4 000 cps				
Time of Test (T)	2	1 166.08	10.8	1%
Subjects (S)	99	605.86		
T x S	198	107.91		
Total	299			

TABLE 5. Mean shifts in bone conduction threshold (in db) from preoperative to 18 weeks following vein plug stapedioplasty, at four frequencies, and corresponding shifts after fenestration (see Shambaugh and Carhart, *9*). Negative values indicate a hearing loss.

Surgical Procedure	*Frequency in cps*			
	500	*1 000*	*2 000*	*4 000*
Vein Plug Stapedioplasty	–2.4	4.9	3.9	–6.1
Fenestration	5.0	10.0	15.0	5.0

The *t* test was applied to differences among test times for each of the three frequencies that demonstrated significant threshold changes from one test time to another. In each case the mean preoperative bone conduction threshold was compared to the six- and 18-weeks thresholds. The six-weeks threshold was then compared to the 18-weeks hearing level.

Results of *t* tests indicate that the six-weeks postoperative bone conduction shifts (see Table 2) at 1 000 cps (4.5 db; $t = 2.64$) and at 2 000 cps (3.1 db; $t = 1.96$) are significant gains. These improved thresholds persisted 18 weeks postoperatively (see Table 2). A significant loss in bone conduction acuity (6.8 db; $t = 3.34$) occurs at 4 000 cps; although an improvement at this frequency occurs between the six- and the 18-week postoperative thresholds, there is still a net loss between the preoperative and the 18-week postoperative thresholds. Slight and non-significant losses (see Table 2) occur between successive thresholds at 500 cps.

When the vein plug stapedioplasty postoperative shifts (18 weeks) are compared to those reported following fenestration (Table 5) it is apparent that the pattern and magnitude of the shifts differ. To correct preoperative bone conduction levels in anticipation of sizeable postoperative changes in threshold seems inappropriate to this surgical procedure.

While no generalized cochlear trauma is suggested by the data of this study, the negative shift in bone conduction threshold (that is, a loss in hearing acuity) at 4 000 cps may be related to this issue. Since high frequency localization is at the end of the cochlea nearest the oval window, it is possible for activity at this window during surgery to adversely influence high tone responses with low frequencies remaining unaffected. However, it seems obvious from this study that the over-all auditory gains dramatically outweigh this modest negative shift.

Summary

Between May and November, 1959, 100 vein plug stapedioplasties were performed. Shifts in air and bone conduction thresholds were tabulated, based upon the pure tone audiometric preoperative and six-weeks and 18-weeks postoperative measurements; for 90% of these cases the result was a closure of the air-bone gap. No significant shift in bone conduction threshold occurred at 500 cps. There was a statistically significant improvement in the bone conduction sensitivity at 1 000 and 2 000 cps. A significant loss in bone conduction acuity occurred at 4 000 cps.

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Perseveration in Stutterers and Nonstutterers

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Psychologists have long been divided on the question of whether perseveration does or does not exist as a generalized group factor. Certain experimenters (*18, 19, 26*) think it does; others (*12, 13, 25*) do not agree. Some investigators (*1, 28*) report studies in which results are only partly compatible with the idea of a group factor; others (*16, 22*), while taking a stand against the existence of a perseverative factor, have admitted that there is some evidence of a limited motor factor but feel that this evidence is not conclusive.

The concept of perseveration has meant many things since the psychiatrist Neisser in 1894 (7) originated the term to describe clinical symptoms of abnormally persistent repetition or continuation of an activity. Writings on the subject in psychology began in 1900 when Muller and Pilzecker added the idea of a process of interference. Gross (*10*) in 1902 referred to the concept as a secondary function of the nervous system. Spearman (*26*, p. 291) wrote about mental inertia, that is, the tendency for mental processes to have a certain lag or inertia. The *New Dictionary of Psychology* (*14*, p. 258) defines perseveration as the tendency of a mental act to continue after the removal of the stimulus.

Types of Perseveration. Stephenson (27), Notcutt (*22*), and Eysenck (*6*, p. 155) are among the several writers who have attempted to classify types of perseveration and perseveration tests. Eysenck presents five main groups of tests of 'this alleged mental function': tests to measure sensory, associative, creative-effort (motor), alternation (motor), and umstellbarkeit perseveration. Sensory tests are based on the 'secondary function' theories of Gross (*10*) and Wiersma (*30*), and are thought to measure the aftereffects (such as a visual afterimage) of sensory stimulation, for instance, the length of time needed for the eyes to accommodate to darkness after exposure to bright light. Associative-perseveration tests are concerned with the tendency for ideas to occur involuntarily once they have been aroused, a typical test requiring the subject to give the color of ink in which the name of some other color is printed. Creative-effort (motor) perseveration tests attempt to measure the ease with which a subject can break an established habit, for instance, can write prose paragraphs in normal fashion and then rewrite them without dotting the *i*s or crossing the *t*s. Alter-

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nation-perseveration (motor) tests measure the ease with which the subject is able to do opposite tasks independently and then in alternation, as drawing squares for a time, circles for a like time, then drawing circles and squares in alternation for a time equal to the total for each separately. Umstellbarkeit tests measure ability to switch from one activity to another (literally, ability to transpose). One such test requires that the subject cancel all the *t*s in a given paragraph, then proceed to cancel all the *e*s in the same paragraph.

Perseveration Experimentation. In previously reported experimentation, the least controversial are the alternation-perseveration tests by which many investigators have identified a perseveration factor. Cattell (*2*) believes that the creative-effort tests are better measures of perseveration than these because they involve the element of dispositional rigidity, that is, the tendency to retain habit patterns. The sensory tests have revealed no general perseveration factor although some researchers (*24, 8*) have obtained positive correlations between these tests. Cattell (*3*, p. 231) points out that 'general positive correlations and intercorrelations consistently appear only in motor perseveration, though some investigators get extensions to certain sensory tests.'

Eisenson (*4*) administered to 30 stutterers and 30 nonstutterers four sensorimotor tests from the Mahler-Elkin Attention Test to measure perseveration and found that stutterers 'show a greater tendency to resist change—a greater tendency for their neurons, once excited, to persist in the original state of excitation—than is the case with normal speakers.'

In a later experiment Eisenson and Winslow (*5*) gave a test of sensory perseveration to 15 stutterers and 20 nonstutterers. The test consisted of tachistoscopically exposed cards on which were colored squares. The subjects reported the number of colors seen and recorded on paper all the different colors remembered. Results showed that the nonstutterers saw significantly more colors and inserted the wrong names in the records significantly less often than did the stutterers. Stutterers erroneously recorded colors presented on a card earlier in the series significantly more often than did nonstutterers. Eisenson concluded that, compared with nonstutterers, stutterers continue longer to react to stimuli which have been removed and cannot adjust to changing conditions as readily as normal speakers.

Lightfoot (*20*) gave a serial color-discrimination test to mild stutterers, severe stutterers, and nonstutterers. A color was flash exposed to the subject, whose task it was to press a key matching the color shown and exposing the next color. It was found that the stutterers worked more slowly but had no longer nor more frequent motor blocks on the apparatus than did the nonstutterers. Stutterers made fewer errors than nonstutterers. Severe stutterers held the response key down longer than did mild stutterers or nonstutterers, a behavior which might be construed as perseverative.

In an attempt to verify the experiments of Eisenson, and of Eisenson and Winslow, Sheets (*24*) gave three series of visual stimuli to 35 stutterers and 35 control subjects. The tests measured subjects' reaction time from (a) darkness to a green light, (b) red light

instantaneously changing to green light, and (c) green light to darkness. Sheets hypothesized that stutterers would have longer reaction times than nonstutterers but found that the differences in reaction time of the two groups were not significant. Sheets' findings did not support Eisenson's conclusions that stutterers are more perseverative than nonstutterers.

In a simultaneously conducted sister experiment in which the design was identical except that auditory rather than visual stimuli were used, Gold (*8*) found no significant differences between stutterers and nonstutterers. Gold interpreted his findings to mean that Eisenson's theory is untenable.

The position that the experiments by Sheets and Gold disprove Eisenson's theory may be questioned. Their findings indicate that stutterers do not perseverate on purely sensory tests; Eisenson's findings are that stutterers are more perseverative than nonstutterers on sensorimotor tests.

Goldsand (*9*) administered a test of sensory perseveration to stutterers and nonstutterers, determining the time required to adapt to a dim light after exposure to a bright one. Her results indicated that stutterers tended to have longer adaptation times and were more variable in their response than nonstutterers. She concluded that stutterers are unable to make rapid shifts in adjustment.

Hill (*15*) performed an experiment with five stutterers and 16 normal speakers, testing the hypothesis that there is a general tendency for repetitions and prolongations to occur upon interruption of a predetermined series of movements. The results indicated few differences between stutterers and normal speakers in either the nature or the amount of abnormal behavior following interruptions of serial muscle activity.

The above investigations comprise the published experimentation relating stuttering behavior to perseveration. In three of them, those by Eisenson (sensorimotor), Eisenson and Winslow (sensory and associative), and Goldsand (sensory), the evidence indicates that stutterers are more perseverative than nonstutterers. In two of them, the experiments of Sheets and Gold (sensory), no significant differences were found between the performances of stutterers and nonstutterers. The studies by Lightfoot and Hill were not directly concerned with perseveration although some aspects were related.

The present experiment was designed to investigate the question of whether stutterers are more perseverative than nonstutterers on tests designed to measure (a) alternating-activity perseveration, (b) dispositional-rigidity perseveration, and (c) sensory perseveration and, as a subsidiary question, whether a perseverative group factor exists for the stuttering population. In this experiment, perseveration is defined as the tendency for a person to persist in the continuance of an activity after the stimulus to that activity has ceased to operate.

Procedure

Subjects. The control group consisted of 82 nonstuttering males, the experimental group of 72 stuttering males. The nonstuttering males ranged in age from 19 to 34 years, with a mean age of 22.5 and a median age of 21.7. The stuttering males ranged in age from

15 to 52 years, with a mean age of 22.7 and a median age of 22.3. For the purposes of this study a stutterer is defined as a person who is diagnosed as a stutterer by a speech and hearing clinic and who is receiving speech therapy for stuttering at the time of the experiment; a nonstutterer is defined as a person who does not consider himself a stutterer and who is not considered a stutterer by his associates at the time of the experiment.

The nonstuttering sample was composed mainly of undergraduate students enrolled in general psychology and speech education classes at the Pennsylvania State University. Subjects for the stuttering sample were obtained from the National Hospital of Speech Disorders in New York City, from the Summer Residential Clinic of the Pennsylvania State University, and from among stutterers attending summer school at the Pennsylvania State University.

It was not considered necessary to match the groups with regard to age or intelligence other than in the most general fashion because previous investigations (*2, 23, 25*) have revealed that perseveration is not significantly related to these two factors.

A pilot study done by the author indicated that perseveration test scores were not affected by extremely high or extremely low degrees of intelligence. Results were evaluated by testing the differences between mean intelligence scores on the Otis Quick Scoring Test of Intelligence, form EM, for nonstuttering persons having the 12 highest and the 12 lowest perseveration ratios on three of the perseveration tests which are described below. The tests were selected at random. In no case was the difference between means statistically significant. The perseveration ratio, used in both the pilot study and the present study and described below, has frequently been used in previous perseveration experiments (*2, 18, 23*).

Perseveration Tests. Ten tests of perseveration, seven motor and three sensory, were given to both the experimental and the control groups. (The motor tests were four alternating-activity and three dispositional-rigidity tests and were considered motor since they required hand and arm motion.) In addition to the 10 perseveration tests, the experimental group was given the Otis Quick Scoring Test of Intelligence, form EM. The vocabulary score and three-part total score of the Pennsylvania State Entrance Examination were available for the control group.

The subjects were instructed to perform each section of each test on the experimenter's commands of 'Begin' and 'Stop.' A stop watch was used to measure time. On the seven motor tests, that is, the four alternating-activity tests and the three dispositional-rigidity tests, the subjects were asked to work as fast as possible.

Alternating-Activity Tests. Each of the four alternating-activity tests (Tests 1, 2, 3, and 4 in the battery of 10) consisted of eight 15-sec parts separated by 7-sec rest periods. In the eight parts of each test the subject was asked to draw two figures, Figure A and Figure B, in the following order: AAAA...; BBBB...; AAAA...; BBBB...; ABAB...; ABAB...; ABAB...; ABAB.... Each of the first four parts thus involved nonalternating activity and each of the last four, alternating activity.

The figures which the subject was asked to draw in the four tests are listed below.

Test 1: Figure A, sidewise eight; Figure B, three discrete lines.
Test 2: Figure A, inverted triangle; Figure B, printed capital *A* sidewise with the open end at the left.
Test 3: Figure A, printed capital *ABC;* Figure B, printed small *abc.*
Test 4: Figure A, square; Figure B, circle.

The tests were scored by dividing the total number of units produced correctly during the nonalternating activity by the total number of units produced correctly during the alternating activity, the quotient being called the 'perseveration ratio.' A correctly produced figure was one which was correct in sequence and which closely resembled the model in shape and angle.

Dispositional-Rigidity Tests. Each of the three dispositional-rigidity tests (Tests 5, 6, and 7 in the battery of 10) consisted of four 30-sec parts separated by 15-sec rest periods; the total time for each of these tests was the same as the total time for each of the alternating-activity motor tests.

Listed below are the tasks required in these three tests.

Test 5: inversed symbol, parts 1 and 3, work simple problems using the mathematical symbols for addition, subtraction, multiplication, and division; parts 2 and 4, work simple problems using the same four mathematical symbols but each with an assigned meaning other than its common one.
Test 6: reversed stroke digit, parts 1 and 3, make digits *1* through *9* in the usual manner; parts 2 and 4, make digits by reversing the stroke so that *1,* for instance, is made from the bottom up.
Test 7: capitalization, parts 1 and 3, copy a prose paragraph in normal handwriting; parts 2 and 4, change initial letters of all words and change all one-letter words, the capitals to lower case letters and lower case letters to capitals.

To score the dispositional-rigidity tests the total number of correct units produced in parts 1 and 3 (which were done in a usual manner) was divided by the total number of correct units produced in parts 2 and 4 (done in an unusual manner) to yield a 'perseveration ratio.' Errors in the first test were inaccurate answers; errors in the second test were misplaced, omitted, unrecognizable, or incorrect digits; errors in the third test were lack or misuse of the capital (three errors), omissions, and additions.

Sensory Tests. The three sensory tests (ambiguous figure, flicker, and spiral) required only an oral answer, usually of one syllable. Total time for the three was about 12 minutes per person. These tests (8, 9, and 10 in the battery of 10) were given in the order listed above, to one subject at a time, and on a testing schedule arranged so that approximately the same number of stutterers and nonstutterers took the test during the same period of the day in order to control any effects of fatigue. All three were timed tests and hence did not involve error scoring.

In Test 8, the ambiguous-figure test, the ambiguous figure was the Necker Wheatstone Outline Cube, a blue ink drawing of a cube on a white 8″ x 5″ card, each line of the cube 5 cm long. A round focus point, 1 mm in diameter, was placed in the center of the cube. The card was handed to the subject with the figure facing away from him. The instructions were:

Hold this card at normal reading distance for you. When I say the word 'go' I want you to turn the card over. On the other side you will see a figure with a dot in the middle of it. Stare at the dot without taking your eyes from it until you hear the word 'stop.' As you stare at the dot the

> figure will appear to change in perspective. Every time it appears to change, say the word 'change.' Do not try to influence the rate of change of the figure. Are there any questions?

The subject reported each time the figure seemed to fluctuate. The mean number of fluctuations in two 1-min periods was recorded. A 30-sec pretest trial was allowed to familiarize the subject with the procedure.

For Test 9, the ascending critical-flicker frequency threshold test, a circle (15 cm in diameter) was cut out of a white screen 25 cm square, and covered with a piece of translucent typing paper. A 5 mm focus point was made with blue ink in the center of the circle. The screen was placed in contact with the face of a stroboscope that had a flash duration of .000005 sec. By a dial control the flicker of the light could be increased from a frequency well below fusion threshold to a frequency well above it. The readings of flicker frequency could be taken from a dial in the top of the instrument.

The subject was seated so that his eyes were 60 in. from the focus point on the white screen. The test was given in a partially darkened room lighted by a candle placed 15 in. to the rear of the stroboscope but invisible to the subject in his seated position. Two minutes of dark adaptation were given to the subject in order to stabilize the size of the pupil of the eye before the test was begun. The instructions to the subject were:

> After two minutes of darkness, I will show you a flickering light on the screen. I can increase the rate of flicker until the light flickers so rapidly that it appears to be an unflickering, fused light. Right at the point where flicker disappears and fusion begins, say the word 'now.' As soon as you say the word 'now,' close your eyes until I say 'open.' We shall repeat the procedure seven times. Are there any questions?

The test consisted of two practice trials and five test trials. The average of the five ascending fusion thresholds was recorded for each person.

For Test 10, the plateau-spiral test, a black disc, a white target disc, and a circular white spiral were used. On the 8 in. black disc was pasted the 7.5 in. white spiral, consisting of a line .5 in. wide which made four revolutions in proceeding from the center to the circumference of the circle. The disc was mounted on a portable phonograph machine in a vertical position so that the spiral was facing the subject. The spiral revolved 78 times per minute and was placed 126 in. from the eyes of the subject. On the same level as the revolving spiral but 30 in. to the right was the 8 in. white target disc, so placed because this distance was found to produce maximum distortion of the target disc. It was necessary to control eyeblink while the subject was looking at the target disc. A pilot study had shown that if a subject stared at the target disc without blinking his eyes, the target disc lost its distorted appearance sooner than it did when the subject blinked continuously while looking at it. Therefore, he was instructed to blink his eyes immediately after each tick of the metronome which was placed beside him and set to tick at a rate of 45 times per minute.

Each subject was asked to look at the revolving spiral for 30 sec. Upon command of the experimenter, he transferred his gaze to the target disc. When the target disc no longer appeared distorted to him the subject said

'now.' The time in seconds that the target disc appeared distorted to the subject was recorded. There were one practice trial and two test trials. The final datum for each subject was the average of the two test trials.

TABLE 1. Means, medians, standard deviations, standard errors, and critical ratios on a series of 10 tests of perseveration administered to groups of nonstutterers (NS) and stutterers (S). On Test 8, lower scores indicate greater perseveration; on all other tests, higher scores indicate greater perseveration.

Test	*Group*	*N*	*Mean**	*Median*	*SD*	*SE*	*CR*
1. Sidewise Eight	NS	62	.97	.97	.15	.019	2.97†
	S	62	1.17	1.12	.51	.064	
2. Inverted Triangle	NS	65	1.06	1.03	.11	.014	3.27†
	S	65	1.14	1.12	.17	.021	
3. ABC	NS	63	1.20	1.20	.13	.017	3.78†
	S	63	1.30	1.27	.16	.021	
4. Square and Circle	NS	60	1.11	1.13	.10	.013	2.24**
	S	65	1.16	1.16	.14	.018	
5. Inversed Symbol	NS	46	1.14	1.15	.13	.020	1.39
	S	53	1.28	1.16	.72	.099	
6. Back Stroke Digit	NS	57	3.72	3.55	.29	.038	1.24
	S	63	3.88	3.63	.98	.123	
7. Capitalization	NS	60	1.13	1.12	.11	.014	1.14
	S	61	1.16	1.11	.18	.023	
8. Ambiguous Figure	NS	52	11.10	9.91	6.63	.920	2.32**
	S	50	8.76	8.50	4.88	.691	
9. Flicker Fusion	NS	51	24.2	23.65	2.06	.289	.404
	S	48	24.6	25.20	2.65	.382	
10. Plateau Spiral	NS	51	15.3	14.00	5.72	.801	2.70†
	S	48	11.9	10.00	6.72	.971	

*Mean perseveration ratio for Tests 1 through 7; mean fluctuations per minute for Test 8; mean fusion threshold for Test 9; mean time in seconds for Test 10.
†Significant at the .01 level.
**Significant at the .05 level.

Results

Reliability coefficients for the 10 tests of perseveration were calculated by the split-half method and corrected by the Spearman-Brown formula. These reliability coefficients were calculated on nonstuttering samples. The number of subjects varies from 52 to 120 because not all subjects could arrange their schedules so as to be available for the administration of the entire battery of tests. In addition, some of the tests were put into the battery during the later stages of its construction and these tests did not have the advantage which certain other tests had of being given to several groups of persons during the pilot experimentation.

The reliability coefficients range from .81 for the inverse-symbols test to .97 for both the ascending critical-flicker fusion threshold and the fluctuation rate of ambiguous figure. The magnitude of the correlations obtained indicates that the measures are of adequate reliability for the purposes of this experiment.

The correlation coefficients between the alternating and nonalternating activity on Tests 1 through 7 range from .22 to .76, with four of the coefficients above .70. The coefficient between alternating and nonalternating activity for the seven tests combined is .81.

On nine of the 10 tests, the performance of stutterers was found to be more perseverative than that of nonstutterers. On one test, the plateau spiral, the nonstutterers had the higher perseveration score. Differences between the mean performances of the two groups were significant (Table 1) on six of the 10 tests: at the 1% level on Tests 1, 2, 3, and 10; at the 5% level on Tests 4 and 8. In other words, there was a significant difference in favor of the stutterers on the four alternating motor tests (Tests 1, 2, 3, and 4) and on one (Test 8) of the three sensory tests. There was a significant difference in favor of the nonstutterers on one of the three sensory tests. There were no significant differences on the three dispositional-rigidity tests and on one of the three sensory tests.

Differences between means for stutterers and nonstutterers on both the alternating and nonalternating activity are small. Differences between the mean *P* ratios are also small, and the stutterers tend to vary more about their means than do the nonstutterers.

There was much overlapping of the test scores of the stutterers and nonstutterers. In spite of significant differences between group means, many of the nonstutterers made higher perseveration scores than many of the stutterers.

To answer the question of whether a general perseveration factor exists, sets of scores for the 10 tests of perseveration were correlated with one another and with intelligence test scores (Otis Quick Scoring Test of Intelligence, form EM). The test scores of 50 stutterers, 44 males and six females, on which there were complete test data were used in computing the correlation coefficients. The mean age and the mean intelligence test score for this selected sample were approximately the same as for the total sample from which it was drawn. It was ascertained before combining the male and female samples that the intercorrelation coefficients on 10 pairs of tests selected at random were

not significantly different for male and female stutterers.

A general factor of perseveration was sought for in the stuttering population, rather than in the nonstuttering population, because the previous tests indicated that perseverative behavior was less apparent in nonstuttering subjects. In other words, it was felt that a perseveration factor might exist in the test scores of stutterers that might not be present in the scores of nonstutterers.

Many of the obtained coefficients are low, with only 16.4% significantly different from zero at the 5% level; 45.5% are negative. These findings do not seem to constitute evidence for a general perseveration factor as conceived in factor analysis terms. Of the intercorrelation coefficients lying within the block of alternating-motor tests (Tests 1 through 4), 50% are significantly correlated with each other. It thus appears that there is a weak common element in the alternating-motor tests but that the tests of dispositional rigidity and the sensory tests have no common element or cohesion. The tests within either one of these latter two areas are no more like each other than they are like tests within another area. Certainly there is no evidence of a general perseveration factor. The number of low and nonsignificant intercorrelations of the perseveration test scores with the scores on the general intelligence tests give evidence that the perseveration test scores are not related to intelligence in stutterers.

Discussion

Because test results showed more perseverative performance for the stutterers than for the nonstutterers on nine of the 10 tests (five of those nine differences significant) and because the tests were found to be essentially unrelated and discrete measures, the question arises as to why the results should thus be so consistently in the same direction.

It is of interest that a contiguous change of set was demanded on all of the tests (Tests 1, 2, 3, 4, and 8) on which scores indicated significantly greater perseveration for the stutterers than for the nonstutterers. On the first four of these, the alternating-motor tests, it was both a motor and a mental change of set; on the other (Test 8, ambiguous figure), it was a mental change of set. The three dispositional-rigidity tests, on which there was no significant difference between the performance of the two groups, are assumed not to involve a contiguous change of set. It may be suggested, however, that the higher (though not significantly higher) scores of the stutterers here may not be unrelated to the more general consideration of over-all facility in performance since these three tests asked for breaking of habit patterns.

A contiguous change of set thus might seem to be the real discriminator between the stuttering and nonstuttering samples. This contiguous change of set, as measured by five of these tests (four alternating-motor tests and one sensory test), however, does not influence test results to the extent that test relatedness is indicated, nor does it provide a common element recognizable as a group factor. It was suggested previously that the number of significant correlation coefficients found when the alternating-motor tests were compared with each other was greater than in

the case of the tests of dispositional rigidity and sensory tests. This finding is taken as an indication that the alternating-motor area is, perhaps, a more cohesive unit than the other areas. However, this cohesion does not extend to the ambiguous-figure test (Test 8), as the low and nonsignificant correlations between this test and all alternating-motor tests revealed. There thus does not seem to be one factor under which all tests that differentiate stutterers from nonstutterers can be subsumed.

One other explanation for the test results presents itself and that is an explanation in terms of tension and inflexibilty of the stutterer as a person. Stutterers are sometimes regarded as tense individuals and, in studies of the cause of this tension, such reasons as oral eroticism (*11*, p. 27) and the learning of fear in speech situations (*17*, p. 193, *31*) have been suggested. Blanton (*11*, p. 11) believes that 'psychological factors are the primary causes of stuttering and that fear states of the stutterer prevent the cortex from exercising control over the organs used in speech.' Coriat (*11*, p. 27) feels stuttering 'represents the resistance against sudden discharges of oral eroticism. As such it should be handled like other forms of morbid anxiety in which there is a sense of internal danger.' Robbins (*11*, p. 83) believes that 'stuttering is one of the many symptoms of psychoneurosis. It appears most frequently in nervous individuals who inherit a tendency to stutter or to exhibit other nervous traits. It is often intermittent, and usually varies in severity with emotional tension. . . .'

To the extent that tests of the present study present a threatening and a challenging situation, the stuttering group, if more anxious as hypothesized, might tend to overreact to the situation with the subsequent increase in tension level. With the increase in anxiety, the rigidity, as well as muscular contraction, is increased, thus hindering the stutterer from performing alternating-motor acts or changing set rapidly. This speculative reasoning is offered as a possible explanation as to why tests demanding a contiguous, rapid change of set discriminated between stutterers and nonstutterers and why other tests failed to discriminate. The critical flicker-fusion test and the plateau-spiral test, the two sensory tests which did not show stutterers to be more perseverative than nonstutterers, did not involve a contiguous and rapid change of set. The same is true of the dispositional-rigidity motor tests, which failed to discriminate between the two groups and which demanded a change of set but not a contiguous and rapid one. The author is not able to explain, at his present level of information, why normal speakers made significantly higher perseveration scores than stutterers on Test 10, the plateau spiral.

It is suggested that the perseverative behavior of stutterers can be adequately explained in terms of such concepts as tension, rigidity, and inflexibility of purpose without resort to a hypothesis of neurological differences between stutterers and nonstutterers or to such constructs as neuromuscular inertia. Possibly there are two types of perseveration. One type might be caused by organic factors, by damage to some parts of the central nervous system. This type of perseveration would then be found in persons with cerebral palsy, aphasia, and traumatic brain damage.

The other type might be associated with psychological factors: relatively intense anxiety and the rigidity, muscular tenseness, and inflexibility of purpose that often accompany such anxiety. Perseveration, in the latter sense might be seen as a defense against anxiety to the extent that perseverative behavior helps to reduce the feelings of ambivalence and confusion that would beset the person if the perseverative set were not maintained. It is suggested that stuttering is associated with and explainable in terms of perseverative behavior of a psychological type, not with perseveration caused by organic impairment. It is interesting to note that the flicker-fusion test of the present study has been used in the past to reveal damage to the central nervous system (27) and that in this study it did not differentiate between stutterers and nonstutterers. Stutterers did not perform as adequately as nonstutterers on tests that would seem to penalize anxious persons.

Summary

Ten tests of perseveration and one group intelligence test were given to 72 male stutterers and 82 male nonstutterers. The tests of perseveration were categorized in three areas, alternating motor, dispositional rigidity, and sensory, in an effort to ascertain whether stutterers were perseverative in some areas and not in others. On five of the 10 tests, the results showed stutterers significantly more perseverative than nonstutterers. One test indicated nonstutterers more perseverative than stutterers.

In general, it was found that stutterers are more perseverative than nonstutterers on activities that demand a contiguous mental, or mental and motor, change of set. It was suggested that stutterers were penalized more severely on these particular types of activities by their anxiety and emotional tensions. The evidence did not support the hypothesis of any influence of a broad underlying factor of perseveration upon stutterers' test results.

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Disfluency of Normal Speakers and Reinforcement

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Learning models have been used extensively to explain observables of stuttering but comparatively little use has been made of behavioral models to study disfluencies of normal speakers. Observables of stuttering have been related to learning in several ways. Among these are a comparison of stuttering adaptation to experimental extinction (*8*), a description of stuttering as a learned anxiety reaction because of the consistency with which stuttering follows specific cues (*9*), and an instrumental conditioning depiction of stuttering because of apparent operant control of amount of stuttering (*2*).

In the limited literature on disfluencies of normal speakers, two studies (*1*, *4*) based on a cybernetic model (7) demonstrated that a breakdown in verbal behavior, overtly similar to stuttering, resulted from a critical time delay in auditory feedback. Stress situations also were found to produce disfluencies in the speech of normal speakers. Penalty, fear of penalty, and the requirement that an individual make and verbally express decisions about ambiguous stimuli resulted in a disorganization of verbal behavior which was similar to stuttering (*3*). Punishment of verbal responses has been found to increase reaction time and has been interpreted in terms of avoidance learning and conditioned anxiety constructs (*5*).

Since some concepts of learning appear to relate meaningfully to stuttering phenomena, the possibility arises that, within the framework of these learning models, disfluencies may be conditioned in the speech of normal speakers.

The purpose of this study was to evaluate the effect of reward and punishment upon verbal behavior, particularly with reference to whether or not disfluencies could be elicited through negative reinforcement.

Procedure

Subjects. The subjects were 12 male and 12 female college students. All were considered normal speakers.

Verbal Task. Eight six-letter nonsense words (cycowa, uwuwid, zykave, yfegab, kixyce, udibed, koziju, ahyjyh), which were assumed to be of low associative value and within the pronouncing capabilities of the subjects, were typed in capital letters on 3″ x 5″ cards, one word to a card. The cards were arranged in the order above, remained in that order for each speaker throughout the experiment, and were turned face down before the experimental task was begun. The speaker's task was to turn one card at a time, read the word, and continue until he

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had read through the cards 30 times, that is, had read 30 x 8 or 240 words. He was told that after he had read each word he would be informed as to whether his pronunciation was 'right' or 'wrong.'

A 1 000 cps beep at 6 sec intervals was the signal for the speaker to turn the card and read the word. Four seconds after the beep, he heard the response of 'right' or 'wrong.' Each subject was tested alone and for each the experimental session lasted approximately half an hour.

Reinforcement Schedules. The speaker was not told that the 'right' and 'wrong' responses to his pronunciation had been programmed on magnetic tape prior to the experimental session. The responses had been recorded in a predetermined sequence as required by the experimental plan but which, of course, had no relation to the subject's pronunciation. In this sequence four different reinforcement schedules of the 'right' (reward reinforcement) and 'wrong' (punishment reinforcement) responses were used:

I. 100% reward and 0% punishment;
II. 66% reward and 33% punishment;
III. 33% reward and 66% punishment;
IV. 0% reward and 100% punishment.

Order of 'right' and 'wrong' in Schedules II and III was random. The four schedules were systematically assigned to different words for different speakers in such a way that in each speaker's total of 240 words he read 60 words under each of the four schedules. Thus, each speaker read a specified two of the eight stimulus words under a particular schedule 30 times. By the end of the experiment each word had been read under all schedules equally often by the 12 male and 12 female subjects.

The extent to which the speakers realized that the 'right' and 'wrong' responses were tape recorded on a predetermined schedule was not known. Three of the 24 speakers stated after the experimental session that they suspected that these responses were programmed on tape; however, their verbal performances did not differ from those of the other speakers. Many of the speakers apparently thought that each pronunciation was evaluated by the auditor, as evidenced by their frequent comment, 'I'm sorry,' when 'wrong' was heard following the saying of a word.

Apparatus. The directions to the subjects, the signal beep, and the 'right' and 'wrong' responses were recorded on an Ampex, Model 350, magnetic tape recorder. The pickup for the voice recordings was an Altec-Lansing, Model 21C, condenser microphone. The signal beep was produced by an audio oscillator, General Radio, Model 1302A, and the interval timing was accomplished by use of an electronic switch, Grason-Stadler, Model 829551, and an interval timer, Grason-Stadler, Model 472. The playback equipment for presentation of the material to the subjects was the Ampex recorder with an associated amplifier which fed the subjects' earphones (PDR-8 receivers). The signal level to the subjects was approximately 80 db (re .0002 d/cm^2).

Measure of Disfluency. Two judges rated each word said by each subject on a nine-point scale of disfluency, where *one* represented fluency and *nine* represented extreme disfluency. Point *five* was assumed to be halfway between *one* and *nine*, the other points

falling at equal distances above and below. The judges were not aware of the schedule of reinforcement. The criterion measure for each subject on each reinforcement schedule was the total score obtained by adding the ratings of the two judges for the 60 words read on that schedule. Criterion scores for each schedule thus could vary from 120 to 1 080.

Results and Discussion

Differences in the degree of judged disfluency among the four reinforcement schedules, evaluated by the Friedman two-way analysis of variance (*6*, pp. 166-172), were significant ($\chi_r^2 = 43.81$; $\chi_r^2{}_{.01}$ with 3 $df = 11.34$). The mean scores were 123.37, 127.41, 133.00, and 155.41 for Schedule I (100% reward and 0% punishment), II (66% reward and 33% punishment), III (33% reward and 66% punishment), and IV (0% reward and 100% punishment), respectively. Analyses using the same test were made between each possible pair among the four schedules. The schedules were significantly different beyond the 1% level, with the exception of the differences between Schedules I and II and between II and III. These χ_r^2 scores were as follows: Schedules I and II, 2.67; I and III, 10.67; I and IV, 20.17; II and III, 13.38; II and IV, 20.17; and III and IV, 20.17 ($\chi_r^2{}_{.01}$ with 1 $df = 6.64$).

A separate evaluation among schedules was made for males and females. The differences among schedules were significant for both groups (males, $\chi_r^2 = 24.93$; females, $\chi_r^2 = 24.65$; $\chi_r^2{}_{.01}$ with 3 $df = 11.34$). The mean scores for males were 123.83, 127.08, 134.25, and 160.08, and for females were 122.92, 127.75, 131.75, and 150.75 for Schedules I, II, III, and IV, respectively.

Since the mean score for the males under Schedule IV (0% reward and 100% punishment) was 160.08 as compared to 150.75 for the females under the same schedule, an evaluation was made by the Mann-Whitney U Test (*6*, pp. 116-127) to determine whether the two groups were significantly different in disfluency. An obtained U value of 55.5 ($U_{.01} = 42$; two-tailed test) indicated a significant difference between the two groups. A test was not made between males and females with respect to the other three conditions because differences between means were very small for the two groups under these conditions.

That the incidence of stuttering is considerably higher among males than among females is a well known fact. If this fact may be interpreted to mean that the female is less susceptible to disorganization of verbal behavior than is the male, then this susceptibility should have been reflected in the scores for the two groups of subjects. Support for this hypothesis was found only at the 100% punishment schedule (Schedule IV) where males were significantly more disfluent than females.

Three further analyses were made for evaluation of scores obtained by the subjects during the reading of the first, second, and third 80 words of the 240 words read. It was felt that perhaps disfluency occurred early in the experiment because of unfamiliarity with the task, but that it might not have persisted as the subjects became more familiar with the words. Inspection of the mean scores for the four reinforcement schedules for each 80 words indicated that there was a gen-

eral decrease in amount of disfluency in time but that there was an increase in the amount of disfluency with an increase in the punishment. The mean scores were 42.71, 45.58, 47.50, and 54.08 for the first 80 pronunciations, and were 40.21, 40.75, 42.33, and 48.83 for the third 80 pronunciations. The χ_r^2 values were 22.94, 53.34, and 39.68 ($\chi_r^2{}_{.01}$ with 3 $df = 11.34$) for the first, second, and third 80 words, respectively. The trend of these values was similar to the trend obtained by the analyses for all 240 words and for males and females separately in that an increase in disfluency accompanied an increase in punishment.

The results of this study indicated that disfluencies were conditioned in the speech of normal speakers as a result of punishment of verbal behavior. The extent to which this result may be related to the development of stuttering may be only surmised; however, the behavior observed in this study does seem similar to what has been described as a learned-anxiety reaction. If an individual becomes disfluent as a result of punishment, and there is a persistence of this disfluency in response to specific word and situation cues, then it is possible that there may be some application of the results found in this study to the understanding of the onset and development of stuttering.

Summary

The effect of a predetermined schedule of reward and punishment upon the verbal behavior of normal speakers was evaluated. The subjects, 12 male and 12 female college students, read a series of nonsense words under four reinforcement schedules. Fluency-disfluency of each speaker saying each word was judged by two trained observers.

The results indicate that normal speakers become disfluent when their verbalizations are punished. Males and females were similarly affected by punishment except that males were more disfluent than females as a result of 100% punishment. The effect of reward and punishment upon verbal behavior was consistent within a short time span.

Theoretical implications concerning the onset and development of stuttering were discussed in relation to the finding that disfluencies were conditioned in the speech of normal speakers as a result of punishment.

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Subject Classification and Articulation of Speakers with Cleft Palates

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The articulation errors of individuals with cleft lips and palates have been surveyed by many investigators. Spriesterbach, Darley, and Rouse (*11*) and McWilliams (*5*) have reported that children and adults with cleft palates are generally retarded in articulation skills and have demonstrated that the pattern of misarticulations can be meaningfully described according to the various classifications of speech sounds. These investigators, however, combined data for their entire subject groups. The results of more recent studies suggest that there may be differences in articulation ability between various subgroups of the cleft palate population. Bzoch (*3*), Counihan (*4*), Morris (*6*), Spriesterbach and Powers (*12*), and Starr (*13*) found differences in articulation skills between subgroups classified according to cleft type (lip-and-palate, and palate-only), although not all differences were significant. Spriestersbach and Powers also reported that articulation proficiency varies partially as a function of the speaker's ability to impound intraoral breath pressure. Byrne, Shelton, and Diedrich (*2*), however, found no differences in articulation skills between cleft palate subgroups classified according to either type of cleft or type of physical management.

In view of the findings of these investigations, it appears that there may be differences in articulatory proficiency between subgroups of the cleft palate population. This study was designed to evaluate several subject classifications in an attempt to assess the extent to which speakers with cleft palates can be meaningfully combined in studying their ability to articulate consonant sounds.

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TABLE 1. Mean percentages of consonant elements of the Templin-Darley Diagnostic Test of Articulation produced correctly by the subject groups which were classified on the basis of type of cleft and pressure ratio, as indicated.

Subject Classification	*N*	*Mean Percentage*	*Range of Percentages*
General Type of Cleft			
Lip Cleft Only	9	97.44	91 to 100
Lip and Palate Cleft	85	69.32	6 to 100
Palate Cleft Only	29	61.31	8 to 100
Type of Palate-Only Cleft			
Soft Palate Cleft	15	65.07	22 to 100
Hard and Soft Palate Cleft	14	57.29	8 to 100
Type of Lip Cleft			
Unilateral	53	70.81	6 to 100
Bilateral	32	66.86	10 to 100
Pressure Ratios			
.90 or more	49	81.40	39 to 100
.51 to .89	18	61.00	6 to 100
.50 or less	23	57.91	26 to 100

Procedure

Subjects. Nine children with cleft lips only, 85 children with cleft lips and palates, and 29 children with cleft palates only were studied. The children ranged in age from three years, six months to 16 years, 11 months, with a mean age of nine years, one month. Other selection criteria were that the children must be Caucasian, be available for examination at the University of Iowa, and exhibit no obvious motor involvement. Of the 114 subjects with palatal clefts, 89 had surgical or prosthetic management performed at various centers in four midwestern states; the remaining 25 subjects had unmanaged cleft palates or had surgical repairs which had broken down.

Articulation Testing. The Templin-Darley Diagnostic Test of Articulation (*16*) was administered to each subject. This picture test consists of 176 test items which include all consonant and most vowel phonemes in the English language. Only the consonant elements were considered in this study. A number of the items are consonant blends which consist of two or three sound elements. Each blend element was treated separately so that the 25 consonants appeared as singles or in blends a total of 215 times.[1]

The articulation test was administered to each child by one of three experienced examiners. Each test sound was scored according to the following classifications: correct production, omission, distortion, or substitution. Substituted sounds were later classified according to whether they were consonants, vowels, or glottal stops.

[1]Considered as vowels and not included in the study were the /ɜ˞/ as in 'bird' (stressed syllabic), /ə˞/ as in 'car' (postvocalic) or as in 'hammer' (unstressed syllabic), /l/ as in 'bell' (postvocalic) or as in 'table' (unstressed syllabic), and /m/ as in 'chasm' (unstressed syllabic).

TABLE 2. Mean percentages of consonant elements, classified according to manner of production, which were produced correctly by the total group and by the subjects classified by pressure ratios.

Subject Classification	*Nasals*	*Glides*	*Stop Plosives*	*Fricatives*	*Affricates*
Total Group	91	79	71	49	47
Pressure Ratios					
.90 or more	96	89	85	66	65
.51 to .89	88	75	64	37	40
.50 or less	84	77	58	40	35

Subject Classification. The articulation data were evaluated according to the following subject classifications: (a) general type of cleft (cleft lip only, cleft lip and palate, cleft palate only); (b) type of palate-only cleft (cleft of the soft palate only, cleft of the hard and soft palate); (c) type of cleft lip (unilateral, bilateral); and (d) oral breath-pressure ratios,[2] hereafter to be referred to as pressure ratios, (.90 or more, between .51 and .89, .50 or less).

Results

Articulation error differences between the various subgroups described above were analyzed. In addition, differences in the frequencies with which various types of errors occurred were evaluated. The criterion measure utilized for these comparisons was the percentage of consonant items correctly articulated. Since scores for the various subgroups were not normally distributed and the distribution form was not similar for all groups, nonparametric statistical procedures were utilized for all analyses (*10*).

Group Comparisons. The number of subjects, mean percentage of correct consonant articulation, and the range of percentages are presented for each of the subject groups in Table 1. Since the nine children with cleft lips only had essentially perfect articulation, they are not considered in subsequent analyses.

When comparisons were made according to cleft type, it was found that children with cleft lips and palates exhibited better articulation than those with cleft palates only, children with soft palate clefts only exhibited better articulation than those children with clefts of both the hard and soft palates, and children with unilateral cleft lips exhibited better articulation than those with bilateral cleft lips. The differences between groups were relatively small, however. In addition, the ranges in percentages in Table 1 indicate that there is a great overlap in articulation scores between the various subject groups and that the within-group variability is extremely large. Intergroup differences for each of the three type-of-cleft classifications were evaluated by Mann-Whitney *U* tests; none of the differences were statistically significant.

The score ranges were also very large for subject groups classified ac-

[2]Oral breath-pressure ratios were computed by dividing the wet-spirometer reading obtained with the nostrils open by the reading obtained with the nostrils occluded (*12*).

TABLE 3. Mean percentages of consonant elements as singles and in blends produced correctly by the total subject group and by the subjects classified by pressure ratio.

Subject Classification	*N*	*Singles*	*Blends*	*Difference*
Total Group	114	70.68	63.89	6.79
Pressure Ratios				
.90 or more	49	84.20	78.59	5.61
.51 to .89	18	65.89	56.11	9.78
.50 or less	23	62.65	53.17	9.48

cording to pressure ratios. The intergroup differences were evaluated by the Kruskal-Wallis one-way analysis of variance and were found to be significant. Individual group differences were evaluated by the Mann-Whitney test. The differences between the group with pressure ratios of .90 or more and the two groups with lower pressure ratios were statistically significant ($P < .01$). The difference between these two groups with lower pressure ratios was not significant.

Speech-Sound Category Comparisons. Differences between various categories of consonant sounds were evaluated for the total subject group and for each of the three pressure-ratio groups.

Manner of Consonant Production. The mean percentages of consonant elements correctly articulated as singles are presented in Table 2 according to manner of production. For the total subject group the order of defectiveness from least defective to most defective was as follows: nasal semivowels, glides, stop plosives, fricatives, and affricates. Evaluation of the over-all differences between the manner-of-production categories by the Friedman two-way analysis of variance indicated that the differences between the five categories were statistically significant. Differences between each possible pair of categories were then evaluated using the Wilcoxon test; all differences were significant except that between fricatives and affricates.

The rank order of the manner-of-production categories was essentially the same for all three pressure-ratio groups; however, the differences in articulation performance between the group with the highest ratios and the other two groups are much greater for

TABLE 4. Mean percentages of voiced and voiceless stop plosives, fricatives, and affricates produced correctly by the total subject group. Only consonant elements tested as singles are considered.

Consonant Elements	*Voiced*	*Voiceless*	*Difference*
Stop Plosives, Fricatives, Affricates Combined	66.49	63.86	2.63
Stop Plosives	79.77	74.31	5.46
Fricatives	54.77	57.50	−3.27
Affricates	49.34	44.30	5.04

the fricatives, affricates, and stop plosives than for the nasals or glides. The largest difference occurs on the fricatives. The previously noted similarity of performances of the two groups with lower pressure ratios was also observed in this analysis.

Singles versus Blends. The difference between the articulation performances for the total subject group on consonants as singles and as blend elements (Table 3) was evaluated with the Wilcoxon test. The difference between singles and blends was statistically significant ($P < .001$): articulation of consonants as singles was significantly better than articulation of consonants in blends.

The Wilcoxon test was also employed in the evaluation of the singles-blends difference for each of the three pressure-ratio groups (Table 3). The differences were significant ($P < .01$), indicating that articulation of singles was better than that of blends for each of the three groups. The tendency for the singles-blends discrepancy to be less for the group with highest pressure ratios than for the other two groups was evaluated by the Kruskal-Wallis test. The differences were nonsignificant.

Voicing. Mean percentages are presented in Table 4 for voiced and voiceless consonant sounds. Only the stop plosive, fricative, and affricate sound

TABLE 5. Percentages of types of articulation errors (distortions, D; omissions, O; substitutions, S) observed for consonants as singles and in blends according to manner of consonant production. Subjects are classified according to oral pressure ability: Group 1, pressure ratios of .90 or more; Group 2, pressure ratios of .51 to .89; Group 3, pressure ratios of .50 or less.

Consonant Elements	*Percentages of Errors*					
	Single Consonants			*Consonants in Blends*		
	D	*O*	*S*	*D*	*O*	*S*
Nasal Semivowels						
Group 1	66	0	34	38	36	26
Group 2	48	0	52	63	17	20
Group 3	0	27	73	58	11	31
Stop Plosives						
Group 1	24	12	64	29	31	40
Group 2	21	13	66	38	26	36
Group 3	13	10	77	34	32	34
Fricatives						
Group 1	46	6	48	47	30	23
Group 2	48	11	41	6	48	46
Group 3	42	11	47	51	25	24
Affricates						
Group 1	47	8	45	0	40	60
Group 2	48	7	45	0	82	18
Group 3	50	7	43	69	13	18
Glides						
Group 1	29	0	71	26	53	21
Group 2	19	19	62	26	38	36
Group 3	0	6	94	36	30	34

elements, tested as singles, were included in this analysis. For the three manner-of-production categories combined, the difference between mean percentages for voiced and voiceless sounds was evaluated by the Wilcoxon test and was significant; the voiced consonants were articulated correctly more frequently than the voiceless consonants. Considering each manner of production separately, the direction of the differences is the same for stop plosives and affricates as for the categories combined; only that difference for stop plosives is significant. For fricatives, however, the voiceless sounds are articulated correctly more frequently than the voiced consonants; the difference is also significant.

Type of Misarticulations. The percentages of the total number of misarticulations which were distortions, omissions, or substitutions are presented in Table 5 for each manner-of-production category and for each of the three pressure-ratio groups. Although no statistical analyses were employed, a number of trends can be noted. For all manner-of-production categories more omissions and distortions and fewer substitutions are observed for blends than for singles. Distortions occur more frequently and substitutions occur less frequently for fricatives and affricates than for stop plosives. This trend is particularly clear when the sounds occur as singles. For nasals, stop plosives, and glides as singles there is a tendency for distortions to decrease and substitutions to increase as the pressure ratios become less. This trend does not appear, however, when fricatives and affricates occur as singles. In general, fewer intergroup differences are observed for blends than for singles.

Considering the types of sound substitutions, more than 40% of the errors on stop plosives as singles were glottal-stop substitutions. The percentage of occurrence was higher for the two groups with lower pressure ratios. For stop plosives in blends, there was a reduction in frequency of occurrence of glottal-stop substitutions; however, the two groups with lower pressure ratios again had higher percentages of glottal stops than did the group with highest ratios. In addition, when stop plosives occurred in blends there was a marked increase of omission errors and a decrease of subsitution errors in comparison to the frequency of occurrence of these errors when these sounds appeared as singles.

When fricatives and affricates occurred as singles, fewer (approximately 10%) glottal-stop substitutions were observed on these than on the plosives. Many of the substitutions for fricatives and affricates were substitutions of sounds differing in place of articulation (for example, /f/ for /s/) or in place and manner of articulation (for example, /p/ for /s/). As in the case of stop plosives, more omission errors were observed for fricatives in blends than as singles. There was not, however, a corresponding shift in occurrence of substitution errors noted previously in the case of stop plosives.

Discussion

Cleft Type Differences. Between-group differences according to cleft type indicate that children with clefts of the lip only have essentially perfect articulation, while children with clefts of only the palate have poorer articulation than those with lip-and-palate

clefts, children with clefts of only the soft palate have better articulation than those with clefts of the hard and soft palate, and children with unilateral clefts have better articulation than those with bilateral clefts. The differences between the lip-and-palate, palate-only, and soft-palate-only groups were not significant although the extreme intragroup variability may have prevented the observed differences from reaching statistical significance in some instances. In spite of their statistical nonsignificance the differences are so consistent in this and previous investigations that a trend has been established conclusively.

Differences in Pressure Ratios. The results of the present study suggest that, of the factors studied, the ability to impound intraoral breath pressure, as measured by the wet-spirometer ratio, best accounts for the variability in articulation performances of children with cleft palates. It appears further that intraoral breath pressure may be a dichotomous variable insofar as it affects speech production. The two groups with pressure ratios of .51 to .89 and of .50 or less did not differ significantly in articulation ability; however, both of these groups were poorer in articulation skills than children with pressure ratios of .90 or above. That this variable may be dichotomous partially explains the relatively low correlation of .40 found by Spriestersbach and Powers (*12*) between wet-spirometer ratios and articulation test scores. Since ability to impound oral pressure is related to the adequacy of velopharyngeal closure (*12*), the dichotomous nature of oral pressure ability would also partially account for the low correlations reported between velopharyngeal opening and consonant articulation (*12, 14*). Subtelny and Subtelny (*14*) have also reported a higher relationship between the amount of velopharyngeal opening and the correct production of stop plosives than of fricatives. The differences in the pattern of misarticulations of stop plosives and fricatives observed in this study are consistent with these findings. In summary, it may be that a speaker with a cleft palate either obtains the degree of velopharyngeal closure necessary for satisfactory production of the various types of consonant sounds or does not. It is not clear, however, what constitutes the 'necessary degree of closure' in terms of these measures.

While the relationships between pressure ratios, the size of the velopharyngeal opening, and measures of articulation ability are relatively low it cannot be concluded that ability to impound oral breath pressure and velopharyngeal closure are not important requisites to satisfactory articulation. Obviously there are mandatory minimal closure and breath pressure ratio requirements as yet unspecified which vary with the type of consonant sound being produced. Furthermore, even though the breath pressure requirements are achieved, the role of a number of other factors such as dentition and faulty learning will limit the strength of the relationship between articulation ability and single measures of physiological and anatomical adequacy of the articulatory mechanism such as that exemplified by measures of velopharyngeal opening during speech.

Although it appears that the ability to impound air in the oral cavity is

the most important factor in the articulation performances of speakers with cleft palates, differences in oral pressure ability account for only a portion of the subject variability in articulation scores. This is best illustrated by the fact that a few subjects with pressure ratios of .89 or less articulated more than 90% of the consonants correctly. If there are needed mandatory minimal closure and pressure ratio requirements for normal consonant production, one must then assume either that the pressure ratios obtained for these 'normally' articulating speakers were spurious or that these subjects were able to achieve normal articulation skills by means of unusually effective compensatory mechanisms. Powers (*8*) conducted a cinefluorographic study of four cleft palate subjects, one of which showed poor velopharyngeal closure as viewed on the cinefluorographic films yet had good articulation. He reports that that subject showed different kinds of articulatory movements than those shown by the other three subjects and he assumed that these atypical movements were compensatory in nature. The subject also showed nasal obstruction and nares constriction which may have assisted in obtaining sufficient instantaneous breath pressure for the production of consonants which were perceived as normal. Observations of nasal obstruction and nares constriction for the subjects employed in the present study were not made, and thus the importance of these two factors cannot be evaluated. It seems clear, however, that regardless of the importance of adequate intraoral pressure and velopharyngeal closure in the production of normal speech, other factors may be equally important in some instances and need further investigation.

Differences in Manner of Production. The articulation differences between various speech-sound categories observed in this study are in agreement with the findings of previous investigations. The articulation skills of children with cleft palates vary with the manner of consonant production; fricatives, affricates, and stop plosives are the most defective sounds, in that order. The three pressure-ratio groups differed more on fricatives than on stop plosive sounds. This finding suggests that more stringent oral pressure requirements exist for production of fricatives and affricates than stop plosives and is supported by the findings of Black (*1*).

Singles-Blends Differences. The findings of this investigation indicate that children with cleft palates have more difficulty with consonants as elements in blends than as singles. Furthermore, the results of the present study are in agreement with those of Morris, Spriestersbach, and Darley (7) in that they suggest that the singles-blends difference in children with clefts is related to the ability to impound air in the oral cavity and, consequently, to the adequacy of velopharyngeal closure. Although the children with high pressure ratios also exhibited differences in the articulation of consonants as singles and in blends, the difference was not as great as those for the groups with lower pressure ratios. For the children with high pressure ratios who presumably had no oral pressure problems, other factors, such as dental abnormalities or the residual effects of a previous pressure problem, may be

operating to produce the singles-blends difference.

Voiced-Voiceless Differences. The results of this study as well as those reported by Spriestersbach, Darley, and Rouse (*11*) indicate that children with cleft palates show better articulation of voiced than of voiceless consonants when stop plosives, fricatives, and affricates were combined. Findings from the present study, however, indicate that the difference between articulation performances on voiced and voiceless consonants is in a different direction for fricatives than for stop plosives. Similar results are obtained when the data of Spriestersbach, Darley, and Rouse are considered separately for each manner of production; voiceless fricatives are articulated correctly more frequently than voiced fricatives. One explanation of this reversal is that voiceless fricatives are consistently mastered at an earlier age than are their voiced counterparts; the opposite is true for the stop plosives (*15*). Thus, the age group studied may influence the voiced-voiceless difference observed on the fricatives. Counihan (*4*) and McWilliams (*5*) studied adolescent and adult subjects with cleft palates for whom the period of articulation development was presumably completed. For their subjects the voiceless sounds were more defective than the voiced for the fricatives as well as for the stop plosives. Thus, it appears that voiced fricatives as well as voiced stop plosives are articulated correctly more often than their voicless cognates when maturation is not a factor.

Error-Type Differences. The relative frequencies of types of articulation errors observed in this study are in general agreement with the results of previous studies (*3*, *4*, *5*, *13*). An observation which has not been previously made is that the type of misarticulation appears to vary according to whether the consonant appears as a single or in blends.

Sherman, Spriestersbach, and Noll (*9*) have also reported that most errors on stop-plosive sounds were glottal-stop substitutions. They concluded that 'glottal stops are substituted for consonant sounds for reasons other than inadequate oral pressure.' The present findings indicate that relative frequency of glottal-stop substitutions is inversely related to the pressure ratio, and that this type of error is related to some degree to the adequacy of intraoral pressure.

General Implications. Only a few of the parameters which might be considered for subject classification have been employed here. Others which might have been considered are: age of child when the palatal cleft was managed, physical dimensions of the cleft, type of physical management employed, and extent of speech therapy and resulting improvement. While some of these parameters have been considered in other studies, further investigation seems indicated.

It seems certain that adequacy of intraoral breath pressure best accounts for the articulatory abilities of cleft palate speakers regardless of where the management was completed. However, caution should be employed in making generalizations from these results to speakers with cleft palates which have been managed in other treatment centers. In one center the decision for surgical or prosthetic management may depend, for example, upon the type of cleft which the child has. In that

case, articulation differences observed between cleft-type subgroups may be more related to the relative effectiveness of that type of management in that center than to any unique characteristics of the subgroups. Thus, the classifications which are relevant in describing articulation performances of speakers in one center may not be relevant in centers where management decisions are based on different criteria.

The primary point to be made from the results of the present study is that failure to consider differences in articulatory proficiency between various subgroups of the cleft palate population may result in the loss of important information. Appropriate subject classification may be useful in evaluating physical management and speech therapy procedures and in specifying the procedures which may provide improved habilitation programs for these individuals.

Summary

The purpose of this study was to determine which of a selected group of subject classifications could be meaningfully used to describe the articulation abilities of individuals with cleft palates. An articulation test was administered to 123 children and analyses were carried out with the subjects classified according to general type of the cleft, type of palate cleft, type of lip cleft, and ability to impound intraoral pressure. Differences between various speech-sound categories were also evaluated.

The results of this study indicate that ability to impound intraoral pressure is an important factor in the articulatory proficiency of children with cleft palates. Differences between subgroups classified according to the type of the cleft were also noted. Many of the differences observed between speech-sound categories appear to be related to oral pressure ability. The conclusion is drawn that it is necessary to subclassify speakers with cleft palates when studying their articulation skills. Failure to consider these subclassifications will result in a loss of information which may have considerable clinical usefulness and theoretical importance.

Summario in Interlingua

Le proposito de iste studio esseva determinar que de un selected gruppo de subjecto classifications potera usate con significantia describer le articulation habilitates de individuals con fissura palatos. Un test de articulation esseva administrate a cento e vinti-tres pupos e analyses esseva complite con le subjectos classificate secundo general typo de le fissura, typo de palato fissura, typo de labio fissura, e habilitate crear intraoral pression. Differentias inter varie speech-sono classifications esseva evalutate alsi.

Le resultatos de iste studio indica le qual habilitate crear intraoral pression es un importante factor in le articulari proficientia de pupos con fissura palatos. Differentias inter subgruppos classificate secundo le typo de le fissura esseva notate alsi. Multe de le differentias observate inter speech-sono classifications pare esser relatate a oral pression habilitate. Le conclusion es redigite que lo es necessari subclassificar parlators con fissura palatos quando studiante lore articulation habilitates. Fallimento

considerar istes subclassifications resultara in un perdita de information que pote habe considerabile utilitate e theoretic importantia.

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Concurrent Repetition of a Continuous Flow of Words

RUSSELL L. SERGEANT

Cherry (*4*) has found that a specific type of speaking while listening, which he calls 'shadowing,' is an extremely simple task. He played tape recordings of prose through headphones, with instructions that the listener should concurrently repeat what he heard. Describing such performance, Cherry (*3*, p. 279) states 'spoken repetition tends to be in irregular detached phrases and, with most people and most texts, is given in a singularly emotionless voice as though intoning. . . . He mouths the words like an automaton and extracts little semantic content, if any.'

Repeating concurrently has been described further by Cherry, Sayers, and Marland (*5*) as a form of clinical treatment for stuttering. They found that stutterers had little difficulty in the task and even without practice could be induced to repeat a message fluently when reassured of their ability to 'shadow.' They reported that five severe cases of stuttering who were trained in the method 'produced a striking improvement in a period of two to four weeks; this improvement has been maintained in all cases. . . .'

The telephone talker plays an important role as a human relay station in voice communications of the armed forces. He listens to messages on earphones and repeats these messages orally to personnel in the immediate vicinity. The relaying process becomes one in which the talker hears one section of a message and repeats it in the silence immediately following. Then he listens to the next section and repeats it, and so forth until the entire message has been relayed. The use of the telephone talker in this way takes approximately twice as much time as would be needed if he could perform his two tasks, listening and talking, simultaneously.

Some stenographers are required to repeat a continuous flow of speech into a 'steno-mask' connected to a recording machine. Later a written transcription is made from the recording. It is well known that translators at international conferences have a similar, more complicated problem. A vital characteristic of all such repeated speech is its intelligibility.

Dual tasks as described above are controlled by a complex of variables. At least three factors affect performance: (a) There is interference with

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the normal speech feedback mechanism, for, in addition to listening to his own voice, the talker has to listen to another voice over which he has no control. (b) The speaker's own voice tends to mask the incoming voice. (c) Attenuation of airborne intensity of the listener's own voice is caused by any microphone encasement he may wear over his mouth. Concentration upon listening, in general terms, always interferes with talking, and disturbances in many other variables inherent in repeating a message impair vocal reproduction in various ways.

Purpose

This investigation evaluates the effect of rate and intensity of presentation, as well as of practice, upon performance in repeating a continuous flow of words. Concurrent repetition, that is, repeating words while hearing them, was measured in terms of intelligibility of the spoken response. PB-50 word lists (*2*) were the stimulus materials. In addition, evaluations of performance were compared with scores from a group intelligence test, tests of pitch, loudness, and rhythm discrimination, and a test of digital auditory memory span.

Experimental Procedures

Subjects. Subjects were 33 naval enlisted men. Each had recently passed a physical examination including a series of audiological tests. Normal hearing was indicated by an audiogram and by routine otological criteria. Two groups of 12 men each were used in the major portion of this study. One group received practice in repeating a continuous flow of words and the other group did not. Because of transfers to new duty stations, only 11 of the 24 subjects in the major portion of this study remained to be tested for memory span. Therefore, an additional nine men were tested to obtain a group of 20 men for comparing digital auditory memory span and repetition of a continuous flow of words.

Psychological and Auditory Tests. Scores on the five tests listed below were available for the 24 subjects used in the major portion of this study.

(a) Intelligence: U. S. Navy General Classification Test.

(b) Rhythm: Test No. 3, Rhythm, from the Seashore Measures of Musical Talent.

(c) Loudness Discrimination: Auditory Test No. 7, Loudness Discrimination for Bands of Noise (2nd ed.), Psycho-Acoustic Laboratory, Harvard University.

(d) Intensity Discrimination: test of intensity discrimination by constants method at 250 cps.

(e) Pitch Discrimination: test of pitch discrimination by constants method at 800 cps.

In addition to the above, a test of digital auditory memory span was given to 11 men from the major portion of this study and nine additional men. Ten lists of numbers containing three to 12 digits each were patterned after Woodworth and Schlosberg (*14*, p. 696). These lists were compiled with the aid of a table of random numbers (*6*, p. 474). Consecutive repetitions in the table were eliminated. Presentation of the lists followed a variation of the method of limits. A light flashing every 0.4 sec was used for timing a constant rate of presentation of the digits of a number.

Stimulus Tape. A tape of three sections was made using a trained speaker who spoke in a 'general American' dialect.

Section I. The first section of the tape was used to obtain a speech reception threshold (SRT). PB-50 List 1 was recorded with each word preceded by the cue phrase 'say the word ———.' Approximately four seconds intervened between adjacent words.

Section II. The second section was used in a pretest trial. PB-50 List 9 was recorded at a rate of 128 words per minute (wpm). The words of the list were divided into five groups of 10 each. The groups were recorded as a continuous flow of speech with 1.0 sec intervals between them.

Section III. The third section was used to obtain three intelligibility scores. PB-50 Lists 4, 6, and 11 were recorded in groups of 10 words of continuous speech with 1.0 sec intervals between groups. Each list was recorded at a different rate. The rates were chosen from the results of a preliminary study in order that a spread of intelligibility scores on the repetitions might be expected. Fast rate was measured at 180 wpm, medium rate at 127 wpm, and slow rate at 68 wpm. Constant intensity was achieved with a VU meter.

The stimulus tape was recorded using an Altec 21D microphone together with a Western Electro-Acoustic microphone complement Model 100B which led to an Ampex 300C tape recorder.

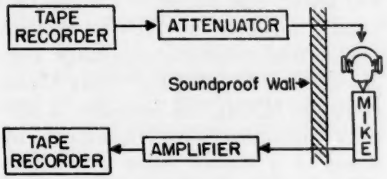

FIGURE 1. Block diagram of instrumentation used in testing.

Test for Concurrent Repetition of a Continuous Flow of Words. Each testing session consisted of three parts. In Part One, a binaural SRT was obtained using Section I of the stimulus tape.

In Part Two, each subject was given a pretest trial to show that he understood the task. The experimenter presented the following instructions orally:

> You are going to hear a list of words similar to the ones you just heard. However, there will be no spaces between the words for you to repeat them. They will sound something like this: 'Book, now, for, cow, chair.' What I want you to do is to repeat back as many of these words as you possibly can. This means you will have to do two things at the same time: one, listen to the words, and two, repeat the words you hear. Your main objective will be to repeat back, clear enough for me to understand, as many of these words as you possibly can. Again, you will have to do two things at the same time, listen and repeat back what you are hearing. Are you ready?

Section II of the stimulus tape was then played binaurally through the subject's earphones at 60 db above his SRT. Any question or difficulties were taken care of at this point.

Part Three began with the following instructions:

> Now you are going to hear three lists similar to the one you just heard. However, these lists will differ in two ways. First, the loudness will change. One list will be the same loudness, another will be much softer, and another will be somewhere in between. Second, the speed at which the words are read will change. One will be the same speed, one will be faster, and one will be slower. You are to repeat back as best you can the words you hear, just like you did a minute ago. Again, this means you will be doing two things at the same time: one, listening, and two, repeating what you are hearing. Remember, your main objective is to repeat back, clear enough for me to understand, as many words as you possibly can. Are you ready?

Section III of the stimulus tape was then played binaurally through the subject's earphones. The order of presentation of three intensities (20, 40, and 60 db) above SRT followed a Latin square. Responses to Part Three were tape recorded. Figure 1 is a block diagram of the instrumentation as used. The tape was played on an Ampex 300C tape recorder, the output of which was fed through a Hewlett-Packard 350A 600-ohm variable attenuator to a headset containing two Permoflux Model PDR-8 phones and MX-41/AR earmuffs. Each subject's responses were received by an Altec 633 microphone which led after amplification to a Magnecorder Model PT63AH.

Scoring of Repetitions. Three intelligibility scores were derived from the repetitions of the third section of the stimulus tape. A written phonetic transcript was made from repeated playbacks of the recorded responses in order to compare the phonetic accuracy of a response with the original PB-50 lists. If any sound of a word was repeated incorrectly or was omitted, that word was scored 'wrong.' If all sounds of a word were repeated correctly and in the proper order, the word was scored 'correct' and was assigned a value of two percentage points. The total possible score for any one list was 100 percentage points.

All phonetic transcriptions were performed by one person. Reliability was evaluated by comparing the original scores for 30 lists with a second set of scores for these same lists obtained approximately three months later. The 'score-rescore' reliability of .98 is high, which would be expected since most

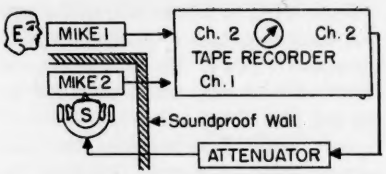

FIGURE 2. Block diagram of instrumentation used during practice period.

responses were clearly correct when not omitted or severely distorted.

Practice Period. Of the 24 subjects used in the major portion of this study, 12 participated in practice sessions which were scheduled twice a day for eight days. Each subject was seen individually during the practice period. All attended at least 14 of 16 scheduled practice sessions. Various intensities and rates of presentation for 15 different PB-50 lists were used. The lists making up the stimulus tape were not used during practice sessions.

Training instructions were informal and consisted primarily of asking the subject to do whatever he could to improve his performance in the task at hand. Encouragement was given during every session. Figure 2 is a block diagram of the instrumentation used for this practice period. The experimenter spoke PB-50 lists into an Altec Type 633 microphone (mike 1). This led to channel two of a Magnecorder Model PT6BN; volume peaks were kept as close as possible to zero on the VU meter. The output of channel two passed through a Hewlett-Packard 350A 600-ohm variable attenuator. Earphones were binaural Permoflux Model PDR-8 in MX-41/AR earmuffs. A subject's responses were monitored by means of a second Altec 633 microphone (mike 2) leading to channel one of the Magnecorder.

TABLE 1. Summary of analysis of variance for evaluating the effect of intensity (I), rate (R), and practice (P) on repetition of a continuous flow of words.

Source	*df*	*ms*	*F*
Between Subjects	23		
P	1	4 640	13.53*
RI_b	2	145	2.37
RIP_b	2	554	1.62
Error (b)	18	343	
Within Subjects	48		
R	2	5 067	56.93†
I	2	3 880	43.60†
RI_w	2	20	4.45
RP	2	132	1.48
IP	2	216	2.43
RIP_w	2	122	1.37
Error (w)	36	89	
Total	71		

*Significant at the .5% level.
†Significant at the .1% level.

An SRT obtained during the first practice session was used as a subject's basal SRT for intensity settings throughout the remaining practice sessions. Intensities were set at 20, 40, and 60 db above this SRT. Three constant rates (fast, medium, and slow) at which the lists were read were approximated by using a stop watch.

Results

A Type IV analysis of variance according to Lindquist's terminology (*10*, pp. 285-288) was used to evaluate effects of stimulus rate and intensity and of practice in repeating a continuous flow of words. Table 1 summarizes this analysis. The *F*s for the several interactions were not significant and suggest that differences arising from combinations of the conditions are no larger than would be expected from chance. The *F* associated with practice is significant beyond the .5% level; the over-all trend is for improved performance in repeating a continuous flow of words to accompany practice. The *F*s for rate and intensity of stimulus presentation are both significant beyond

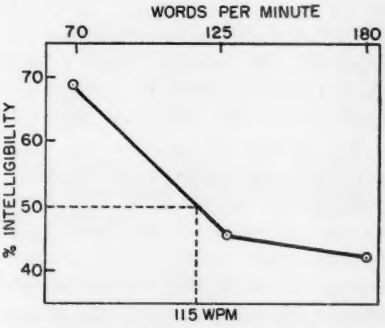

FIGURE 3. Graph of mean intelligibility scores for different rates of stimuli presentation.

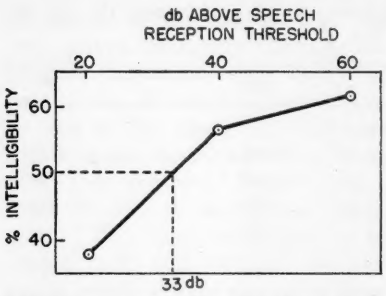

FIGURE 4. Graph of mean intelligibility scores for different intensities above SRT of stimuli presentation.

the .1% level; a slower rate and a higher intensity tend to accompany improved performance on the task of repeating.

Average intelligibility of responses at the slow rate of stimulus presentation was 69%; at the medium rate, 45%; and at the fast rate, 42%. For the three intensities of stimulus presentation, average intelligibility of responses was 38% for 20 db above SRT, 56% for 40 db, and 62% for 60 db. These means are plotted in Figures 3 and 4. The graphs cross 50% intelligibility at a rate of 115 wpm and at an intensity of 33 db above SRT. Thus, if the rate of presentation of words in a PB-50 word list were less than 115 wpm and the intensity were greater than 33 db above SRT, an intelligibility score above 50% would be expected.

Ten of the 12 subjects who participated in the training period achieved intelligibility scores of at least 70% on one or more of the three post-practice test scores. Five subjects scored 85% or higher. It seems reasonable to assume that under the proper conditions of rate and intensity some persons can be trained to repeat a message heard concurrently with more than 90% intelligibility.

Pearson *r*s were computed to evaluate relationships between the intelligibility scores of the responses to the stimuli and each of six psychological and/or auditory tests. None of these correlations is significantly greater than zero except the one associated with the rhythm test. A *t* test showed the *r* of .54 to be significant beyond the .01 level. Hence, scores on the rhythm test of the Seashore Measures of Musical Talent appear to be positively related to scores on the task studied here.

Discussion

The improvement observed in this study, revealing that with periodic practice sessions young men improve in their performance in repeating while listening to words in a continuous flow, shows the feasibility of teaching such a task when it is necessary.

In a preliminary study of adaptation through performance, a group of subjects responded to three different lists which were presented in succession at a constant intensity and rate. A significant difference was observed between the second trial and each of the others. The mean difference in performance between the first and third trials did not reach significance. If the average intercorrelation of trials is used to indicate reliability of the measures of performance (*9*, pp. 280-281), the typical value for a single trial is of the order of .61, and that for the sum of the three trials is .83. Such results are interpreted to mean that the improvement in the major study reported here (for the group of persons who received eight days of practice) was not an artifact attribu-

table to short-term adaptation to the experimental task.

The data of the present study also indicate that the concurrent repetition is most adequately performed by persons who have good rhythmical sense. The relationship between stuttering and various rhythmical tasks has been described in clinical reports (7, p. 171, *1*, p. 95) and controlled experiments (*11*, *12*). It is possible that training in the task improves one's performance in the rhythmical coordination necessary for fluent speech.

Eisenson (7, p. 235) and Eisenson and Horowitz (*8*) have stated that stuttering is generally reduced when communicative meaning is eliminated. When speech has no meaning, speaking becomes a relatively easy task for the stutterer. For 'shadowing,' Cherry (*3*, *4*) found that the performer has little knowledge or meaning attached to repetitions.

Two advantages seem to support the use of the 'shadowing' technique in a program of speech therapy with stutterers: (a) the stutterer can perform a speech task which is related to rhythmical ability; (b) propositional content is at a minimum for the person who listens to and concurrently repeats the speech of someone else. This may explain the successful results reported by Cherry, Sayers, and Marland (*5*) when 'shadowing' was employed in therapy with severe stutterers.

Van Riper (*13*) considers 'echo-speech,' or 'shadowing,' as a device for enabling the therapist to show the stutterer how to modify blocking in the direction of lessened abnormality. As the stutterer speaks, his speech is concurrently repeated by the therapist until there is a block, and then the therapist uses a method of pulling out of the block. Van Riper also describes another use of 'shadowing.' The therapist stutterers while the stutterer simultaneously repeats him. The stutterer's task is to resist the blockings and hesitations of the therapist.

Summary

This study was concerned with oral concurrent repetition of an auditory stimulus consisting of a continuous flow of words to investigate the effects upon the intelligibility of the oral repetitive performance of (a) the rate and the intensity at which the stimulus words were presented and (b) practice. In addition, scores for six psychological and auditory tests were correlated with intelligibility scores. The following conclusions were drawn:

(a) Intelligibility scores are higher with increased intensity of heard speech, and with practice.

(b) Intelligibility scores are higher when the rate of stimulus presentation is decreased.

(c) A positive relationship exists between intelligibility scores and scores on Seashore's rhythm test.

The suggestion is made that under proper conditions of rate and intensity some persons might be trained to perform with more than 90% intelligibility.

Concurrent repetition, or 'shadowing,' is discussed in relation to therapy with stutterers.

Summario in Interlingua

Iste studio esseva concernite con oral concurrentia repetition de un auditive stimulo consistente de un continue

flucto de vocabulos investigar le effectos sur le intelligibilitate de le oral repetitive performance de (a) le rata e le intensitate a que le stimulo vocabulos esseva presentate e (b) practica. In plus, numero de punctos pro sex psychologic e auditive tests esseve correlatate con intelligibilitate numero de punctos. Le sequente conclusions esseva redigite.

(a) Intelligibilitate numero de punctos esse supere con augmentate intensite de audite speech, e con practica.

(b) Intelligibilitate numero de punctos esse supere quando le rata de stimulo presentation es discrescite.

(c) Un positive relation existe inter intelligibilitate numero de punctos e numero de punctos sur Seashore's periodicitate test.

Le suggestion es face que sub proprie conditions de rata e intensitate alicun personas essera trainate complir con plus de novanta percent intelligibilitate.

Concurrentia repetition, o 'umbrante,' es discutite in relation a therapia con balbutiators.

Acknowledgment

The author expresses appreciation to Mr. James Green and other personnel of the Acoustic Laboratory, U. S. Naval School of Aviation Medicine, Pensacola, Florida, for providing assistance in the pilot study which led to the formulation of this investigation.

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Phonetic Elements and Perception of Nasality

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DOROTHY SHERMAN

Probably more has been written about nasality than about any other voice quality disorder. The extensive literature on the subject, however, deals mostly with its physiological and acoustical aspects. Comparatively little has been written about how it is perceived, that is, about factors and conditions with which its impact upon the listener may vary.

The basic problem of the present study was to evaluate the relative effects of certain phonetic elements upon the perception of nasality. The questions asked were these: (a) Does degree of perceived nasality vary from vowel to vowel? (b) Does degree of perceived nasality of the syllable vary with voiced, voiceless, plosive, fricative, front, and back consonant environments? (c) If there are trends of degree of nasality dependent upon changes of phonetic elements, are these trends the same for nasal voices and so-called 'nonnasal' voices?

Procedure

Selection of Material. Vowels used were [i], [ɛ], [æ], [ʌ], [ɑ], [ʊ], [u], selected primarily to be representative of the range of articulatory positions of the tongue, mandible, and lips during vowel production. They were also chosen to facilitate comparisons with earlier studies.

The selection of consonant environments was governed, in part, by evidence (*13*) indicating that vowels adjacent to voiced consonants may be judged more nasal than vowels in voiceless environments and that places of articulation of consonants (front and back) may influence judgments of severity of nasality. Since duration, frequency, and intensity of the vowel might possibly be related to degree of perceived nasality, the selection of environments was also based upon their known effect upon these physical characteristics of vowels. Several investigators have studied the effect of various consonant environments on the physical characteristics of the vowel. Cooper and others (*3*) suggested some time ago that the physical characteristics of vowels are altered by adjacent consonants. House and Fairbanks (*8*), concerned with the influence of 12 consonant environments on the duration, fundamental frequency, and relative power of six vowels, showed that the vowels in voiced environments were longer in duration, lower in fundamental frequency, and greater in power

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than the same vowels in voiceless environments, and that both the manner of production and place of articulation of consonants influenced these same vowel characteristics.

The types of environments used, then, were voiced and voiceless, plosive and fricative, and front and back. The individual consonants were [t], [d], [k], [g], [f], [v], [s], and [z].

Each of the seven vowels was combined with each of the eight consonants to form 56 consonant-vowel-consonant syllables, with the same consonant in the initial and final positions in each syllable. Each of the seven vowels was included also in isolation. The final syllable list thus contained 63 items.

Selection of Voices. The experimental stimuli consisted of tape recordings of the syllables by each of 20 adult male voices, 10 nasal and 10 'nonnasal.' These voices were selected from 25 clinically diagnosed as functionally nasal and 25 judged as 'nonnasal,' that is, as free from unpleasant nasality. From tape recordings[1] of connected speech by these 50 voices, three listeners who had had experience in diagnosis of voice disorders selected a group of noticeably nasal voices and a group of voices free from unpleasant nasality. Recordings of the syllable list were made by each of these voices. The same three listeners then judged these recordings for presence or absence of noticeably unpleasant nasality. The listeners unanimously agreed that 10 voices were unpleasantly nasal and that 10 voices were not unpleasantly nasal. These two groups of 10 voices each were used for the experiment.

Recording Procedure. Each speaker practiced the syllable list with the experimenter prior to recording the tapes to be used in the experiment. A carrier phrase, 'I will say,' immediately preceded the syllable and then the syllable was spoken three times. The subjects were instructed to maintain a level inflection with approximately the same loudness from syllable to syllable. Monitoring was done by the experimenter with the aid of a VU meter.

The experimenter and an additional listener checked each recorded syllable against the stimulus list. Any syllable judged by either listener to be an unsatisfactory example of the intended syllable or to deviate from a reasonably level inflection was re-recorded by the subject until a satisfactory production was obtained.

The syllable lists were recorded in a sound-treated room at a tape speed of 15 ips. The recording microphone was an Electro-Voice, Model 650, and the tape recorder was a Presto RC 10/24.

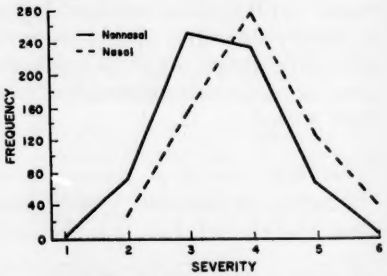

FIGURE 1. Distributions of median scale values of severity of nasality on a seven-point scale for 1 260 speech samples (isolated vowels and consonant-vowel-consonant syllables). Midpoints of severity intervals are given along the abscissa.

[1]The passage read was the first paragraph from 'The Rainbow Passage' (*5*, p. 127).

Preparation of the Experimental Tape. The experimental tape included recordings of the 63 syllables spoken by each of the 20 voices. The carrier phrase and the first production of each syllable were cut from the tape so that each sample in the experimental tape consisted of two productions of a syllable. The total thus was 1 260 two-syllable samples. These samples were arranged for presentation in random order with the restriction that no two samples from the same voice were placed adjacent to each other.

Sample numbers separated from each other by 3 sec intervals were recorded on a tape. The experimental samples were then spliced into this tape, the two productions of a syllable immediately after a sample number.

Scaling Procedure. The listeners were 35 advanced students with training in the diagnosis of voice quality deviations. They first became acquainted with the range of nasality for the 20 voices by listening to recordings of passages by four of the voices selected by three experienced listeners as the two least nasal and the two most nasal. To further acquaint the listeners with the range of nasality, 20 syllables from the experimental tape were played, 10 representing least nasality and 10 representing most nasality. These had been selected from a group of 40 on the basis of median scale values obtained from the responses of 27 experienced listeners who had rated the syllables on a seven-point equal-appearing-intervals scale of nasality. The 40 syllables, with all vowels and consonant environments represented, had been selected by the experimenters as being representative of the extremes.

TABLE 1. Summary of analysis of variance for evaluating differences among vowels, among environments, and between groups, with respect to mean scale values of severity of nasality.

Source	*df*	*ms*	*F**	$F_{.05}$†
Between Speakers (S)	19			
Groups (G)	1	85.55	7.81	4.41
Error (b)	18	10.96		
Within Speakers (wS)	1 240			
Vowels (V)	6	47.17	66.44	2.25
Environments (E)	8	14.20	25.82	2.02
VE	48	.99	9.00	1.00
VG	6	.10	.14	2.25
EG	8	.81	1.47	2.02
VEG	48	.17	1.54	1.00
Error (w)	1 116			
$Error_1$ (w)	108	.71		
$Error_2$ (w)	146	.55		
$Error_3$ (w)	862	.11		
Total	1 259			

**F* ratios: $ms_G/ms_{error(b)}$; $ms_V/ms_{error1(w)}$; $ms_E/ms_{error2(w)}$; $ms_{VE}/ms_{error3(w)}$; $ms_{VG}/ms_{error1(w)}$; $ms_{EG}/ms_{error2(w)}$; $ms_{VEG}/ms_{error3(w)}$.

†$F_{.05}$ is the tabled value for the nearest given *df*.

For rating of the 1 260 experimental samples a seven-point equal-appearing-intervals scale was employed, with *one* representing least severe nasality and *seven* representing most severe nasality. For practice the last 50 of the 1 260 samples were rated at the beginning as well as at the end of the experiment. A reliability estimate was provided for by repetition of the first 100 samples at the end of the listening session. The listeners thus received practice on 150 samples. In the analysis of the data the scale values from the first presentation of the last 50 samples and the first presentation of the first 100 samples were not used.

There were two listening sessions, each one lasting approximately two hours, with a brief rest period each half hour. The procedure for the second session, one day later, was the same as that for the first, with the instructions, training tape, and the 50 practice samples repeated before the experimental task.

Instrumentation for the listening sessions, which were conducted in a sound-treated room, consisted of an Ampex Model 350 tape playback, a McIntosh

TABLE 2. Mean severity of nasality scale values of each vowel and each consonant-vowel-consonant syllable for each of two groups, nasal and nonnasal.

Environments	*Vowels*							*Means*
	[i]	[ɛ]	[æ]	[ʌ]	[ɑ]	[ʊ]	[u]	
Nasal Group								
[t]	3.55	3.35	4.73	2.95	4.32	3.14	2.84	3.55
[d]	3.86	4.12	4.56	3.94	4.31	4.12	3.80	4.10
[k]	3.72	3.68	4.64	3.07	3.84	2.75	2.98	3.52
[g]	4.40	4.20	4.32	3.69	4.45	3.81	3.62	4.07
[f]	3.81	4.17	5.44	3.49	4.52	3.57	3.30	4.04
[v]	4.07	4.38	4.96	3.77	4.39	3.73	3.54	4.12
[s]	3.96	3.79	5.06	3.56	4.41	3.48	3.34	3.94
[z]	4.12	4.25	4.95	4.17	4.77	3.76	3.94	4.28
[–]*	4.05	4.62	5.12	3.98	4.47	3.51	3.24	4.14
Means	3.95	4.06	4.86	3.62	4.39	3.54	3.40	
Nonnasal Group								
[t]	3.02	2.75	3.87	2.42	3.66	2.61	2.10	2.92
[d]	3.49	3.51	4.17	3.46	4.02	3.47	3.20	3.62
[k]	2.85	2.70	3.83	2.40	3.28	2.24	2.42	2.82
[g]	3.82	3.66	3.89	3.22	3.76	3.18	3.11	3.52
[f]	3.23	3.47	4.67	2.93	4.28	2.77	2.65	3.43
[v]	3.80	3.53	4.48	3.42	4.04	3.58	3.36	3.74
[s]	3.09	3.45	4.42	2.91	3.90	2.90	2.64	3.33
[z]	3.79	3.68	4.49	3.33	4.15	3.59	3.46	3.78
[–]*	3.95	4.42	5.11	3.60	3.88	3.52	3.03	3.93
Means	3.45	3.46	4.32	3.08	3.88	3.10	2.88	

*No-consonant environment, that is, isolated vowel.

Model 20-W-2 amplifier, and an Altec-Lansing 604 B speaker.

Results

Scale Values. The 1 260 median scale values range from 1.10 to 6.41, with a range from 1.10 to 6.23 for the nonnasal group and from 1.60 to 6.41 for the nasal group. The distributions for the two groups are shown in Figure 1. Each is approximately symmetrical with the mean and the median coincidental (difference of only .01 in each case).

Reliability. A Pearson r of .89 was obtained as an estimate of the relationship between two sets of scale values for the first 100 samples. The difference between scale-value means of the two trials, 3.64 and 3.71, respectively, is small, .07, and nonsignificant ($t = .40$). For the 1 260 scale values, the Q values, which measure the dispersion of judgments, range from .31 to 1.68, with a mean of .99 and a standard deviation of .20.

Differences between Nasal and Nonnasal Voices. The data were initially evaluated by an analysis of variance, classified by Lindquist (*12*) as a Type VI design, with the following factors: groups, vowels, environments, and speakers. The mean scale value of severity of nasality for the nasal group, 3.98, is, as expected, significantly larger (see Table 1) than the mean for the nonnasal group, 3.45. The interactions between vowels and groups and between consonant environments and groups are not significant. The assumption may thus be made that the trends of severity of nasality for vowels averaged over environments and for environments averaged over vowels are the same for the two groups. The triple interaction of groups and vowels and consonant environments is, however, significant. The interaction between vowels and consonant environments is thus different for the two groups: that is, with respect to severity of nasality, the relationship between consonant environments and vowels for the nasal group differs from that for the nonnasal group. It is to be noted, however, that the obtained F is small, 1.54 and is significant because of the large numbers of degrees of freedom. Under this circumstance a relatively weak interaction may prove significant. Inspection of the data indicates that mean scale values for the vowel [æ] (see Table 2 for obtained means) are one important source of the significant triple interac-

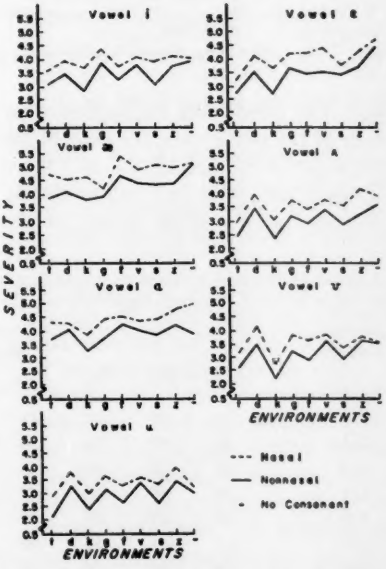

FIGURE 2. Mean severity of nasality scale values for each vowel in each of the environments for each of the two groups, nasal and nonnasal.

TABLE 3. Summary of analysis of variance for evaluating differences among vowels (data for [æ] omitted), among environments, and between groups, with respect to mean scale values of severity of nasality.

Source	*df*	*ms*	*F**	$F_{.05}$†
Between Speakers (S)	19			
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VG	5	.12	.18	2.37
EG	8	.62	.92	2.02
VEG	40	.17	.47	1.00
Error (w)	954			
$Error_1$ (w)	90	.66		
$Error_2$ (w)	146	.67		
$Error_3$ (w)	718	.36		
Total	1 079			

*F ratios: $ms_G/ms_{error(b)}$; $ms_V/ms_{error1(w)}$; $ms_E/ms_{error2(w)}$; $ms_{VE}/ms_{error3(w)}$; $ms_{VG}/ms_{error1(w)}$; $ms_{EG}/ms_{error2(w)}$; $ms_{VEG}/ms_{error3(w)}$.

†$F_{.05}$ is the tabled value for the nearest given *df*.

tion. The trends over environments for each of the two groups for each vowel are represented graphically in Figure 2, where the vowel [æ] may be readily identified as a marked source of the interaction between groups and environments. It seemed possible that the significant triple interaction was the result of the nonadditive effects of the data for [æ] alone. For this reason

TABLE 4. Differences between corresponding means for the nasal and nonnasal groups for each vowel in isolation and each consonant-vowel-consonant syllable.

Vowels	*Environments*									*Means*
	[t]	[d]	[k]	[g]	[f]	[v]	[s]	[z]	[–]*	
[i]	.53	.37	.87	.58	.58	.27	.87	.33	.10	.50
[ɛ]	.60	.61	.98	.54	.70	.85	.34	.57	.20	.60
[æ]	.86	.39	.81	.43	.77	.48	.64	.46	.01	.54
[ʌ]	.53	.48	.67	.47	.56	.35	.65	.84	.38	.55
[ɑ]	.66	.29	.56	.69	.24	.35	.51	.62	.59	.50
[ʊ]	.53	.65	.51	.63	.80	.15	.58	.17	–.01	.44
[u]	.74	.60	.56	.51	.65	.18	.70	.48	.21	.51
Means	.64	.48	.71	.55	.61	.38	.61	.50	.21	

*No-consonant environment, that is, isolated vowel.

a similar analysis was made with the data for [æ] omitted. The results are summarized in Table 3. In this second analysis, all interactions with groups are nonsignificant, with resultant *F*s of less than 1.00. All trends for nasal and nonnasal voices may thus be assumed to be the same, except for the vowel [æ]. On this basis, data for the two groups are pooled for several of the analyses.

Although the interactions with groups are nonsignificant, the obtained mean scale value differences between groups on individual items of the experimental material vary from practically no difference, .01, to .98. It seems possible that the larger deviations from parallelism of trends for the two groups might be of some importance in interpretation of results. Differences are reported in Table 4.

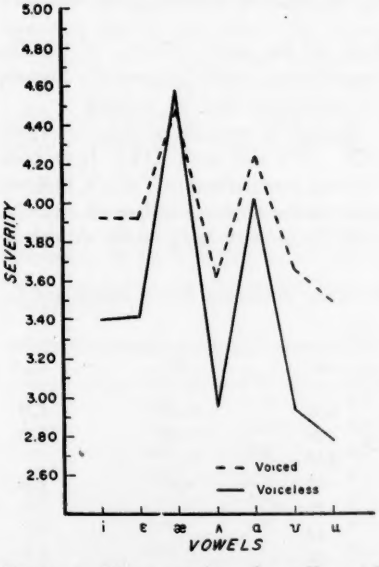

FIGURE 3. Mean severity of nasality scale values for vowels in voiced consonant environments and in voiceless consonant environments for the nasal and nonnasal groups combined.

Interaction between Vowels and Environments. The significant interaction between vowels and environments, for both analyses summarized in Tables 1 and 2, indicates that the individual consonant environments exert relatively different influences from vowel to vowel.

To determine whether the differential effects of individual environments from vowel to vowel are related to two of the types of environment, the data were again evaluated by the same type of analysis of variance but with a breakdown of the environments factor into two additional factors: voicing (voiced and voiceless) and manner of production (fricative and plosive). Since the consonant environments could not be equally divided between front and back place of articulation, these classifications could not be included in this analysis. The complete details of the results, which are highly similar to those reported in Tables 1 and 2, need not be considered here. Important to consider are the significant interactions between voicing of consonant environments and vowels and between manner of production of consonant environments and vowels. The trends of severity from vowel to vowel for the two classifications of voicing, averaged for nasal and nonnasal groups, are shown in Figure 3. The graphical presentation shows that, except for the vowel [æ], for which there is a reversal of .10 scale value, the syllables with voiced environments were judged to be more severely nasal than those with voiceless environments. A similar graphical presentation for manners of

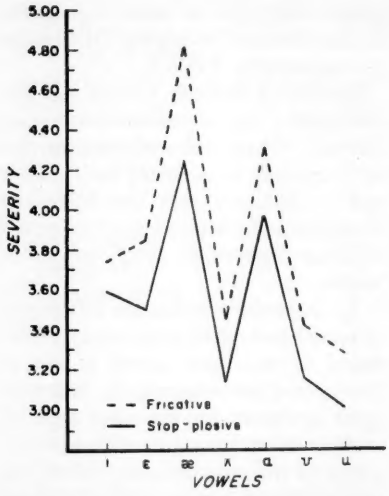

FIGURE 4. Mean severity of nasality scale value for vowels in fricative consonant environments and in plosive consonant environments for the nasal and nonnasal groups combined.

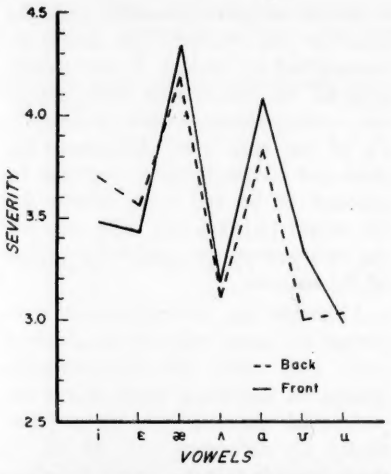

FIGURE 5. Mean severity of nasality scale values for vowels in front consonant environments and in back consonant environments for the nasal and nonnasal groups combined.

production, fricative and plosive, is shown in Figure 4. In this instance, the syllables with fricative environments were consistently perceived as more nasal than the syllables with plosive environments. It was thus assumed that tests of the main effects, to be discussed later, should be made for manner of production and for voicing.

Results of analysis of data for front ([t], [d]) and back ([k], [g]) consonants, summarized in Table 5, indicate that the interaction of place of articulation, front and back, with vowels is

TABLE 5. Summary of analysis of variance for evaluating differences among vowels and between front and back consonant environments.

Source	*df*	*ms*	*F**	$F_{.05}$†
Vowels (V)	6	8.38	49.29	2.25
Environments (E)	1	.29	2.42	4.38
Speakers (S)	19	4.37		
VE	6	.40	4.44	2.25
VS	114	.17		
ES	19	.12		
VES	114	.09		
Total	279			

**F* ratios: ms_V/ms_{VS}; ms_E/ms_{ES}; ms_{VE}/ms_{VES}.
†$F_{.05}$ is the tabled value for the nearest given *df*.

TABLE 6. Mean severity scale values, with data pooled for nasal and nonnasal groups, for syllables with voiced, voiceless, fricative, and plosive consonant environments, with no-consonant environment, and with all environments combined. The critical difference, $t_{.05}(2ms_{error}/n)^{1/2}$, necessary for significance at the 5% level is .55 for voiced, voiceless, fricative, and plosive environments, and .53 for combined and no-consonant environments.

Vowels	*Environments*					
	Combined	*None*	*Voiced*	*Voiceless*	*Fricative*	*Stop-Plosive*
[u]	3.14	3.14	3.50	2.78	3.28	3.01
[ʊ]	3.32	3.51	3.66	2.93	3.42	3.16
[ʌ]	3.35	3.79	3.62	2.96	3.45	3.14
[i]	3.70	4.00	3.92	3.40	3.73	3.59
[ɛ]	3.76	4.52	3.92	3.42	3.84	3.50
[ɑ]	4.14	4.17	4.24	4.03	4.31	3.96
[æ]	4.59	5.12	4.48	4.58	4.81	4.25

significant. The trends over vowels for severity of nasality are shown in Figure 5. From inspection of this graph, it is readily apparent that the differences between corresponding means vary in direction and in size from one vowel to another to such an extent that a test of the main effect of environments (place of articulation) could not be usefully interpreted. Voiced and voiceless consonant environments are counterbalanced for the comparison between front and back consonant environments; and all consonant environments for this comparison are plosives. Thus no explanation for the significant interaction is readily apparent.

Differences among Vowels. The mean severity ratings for vowels in the various types of environments, except

TABLE 7. Mean scale values of severity of nasality, with data pooled for nasal and nonnasal groups, of each vowel in each of the environments. The critical difference necessary for significance at the 5% level between environments for a single vowel is .47.*

Environments	*Vowels*						
	[i]	[ɛ]	[æ]	[ʌ]	[ɑ]	[ʊ]	[u]
[t]	3.28	3.05	4.30	2.68	3.99	2.87	2.47
[k]	3.28	3.19	4.23	2.73	3.56	2.49	2.70
[f]	3.52	3.62	5.06	3.21	4.40	3.17	2.97
[s]	3.52	3.82	4.74	3.23	4.16	3.19	2.99
[d]	3.68	3.82	4.37	3.70	4.16	3.80	3.50
[v]	3.95	3.96	4.72	3.59	4.22	3.66	3.45
[z]	3.95	3.97	4.72	3.75	4.46	3.68	3.70
[–]	4.00	4.52	5.12	3.79	4.17	3.51	3.14
[g]	4.11	3.93	4.10	3.46	4.11	3.50	3.37
Means	3.70	3.76	4.60	3.35	4.14	3.32	3.14

*Critical difference = $t_{.05}(2ms_{error}/n)^{1/2}$. See upper half of Table 1 for error term employed.

TABLE 8. Summary of *F* tests for evaluating differences in mean scale values of nasality between corresponding classifications for the two factors of voicing and manner of production. Tests are for differences between the following environments: (a) voiced and voiceless plosives; (b) voiced and voiceless fricatives; (c) voiced fricatives and voiced plosives; and (d) voiceless fricatives and voiceless plosives.

Source	*df*	*ms*	ms_{error}	*F*
Voicing				
Plosives	1 and 18	54.69	.98	55.81
Fricatives	1 and 18	12.37	.98	12.62
Manner				
Voiced	1 and 18	3.36	1.17	2.87
Voiceless	1 and 18	32.60	1.17	27.86

front and back places of articulation,[2] and in all environments combined appear in Table 6. For any one of these classifications, there are significant differences among vowels. The differences necessary for significance at the 5% level are given in the legend of Table 6. For all environments combined, the obtained order of vowels with respect to increasing severity of nasality is [u], [ʊ], [ʌ], [i], [ɛ], [ɑ], and [æ]. Under the assumption of no interaction between vowels and environments this obtained order for environments combined is the best approximation of the true order: that is, experimental error is minimized by averaging. Comparison of the means for the several types of environment with the corresponding means for environments combined reveals only nonsignificant reversals of order. In view of the high consistency, there is strong evidence that the obtained order of severity is, in general, fairly stable for the environments under consideration.

[2]Omitted here because of interaction between vowels and places of articulation.

Differences among Environments. The mean nasality scale values for each vowel in each individual environment are reported in Table 7. The mean scale values for the vowel [ɑ] are least affected by the environments. The only significant differences for this vowel are between the [k] environment and each of the other environments except for [t], and between the [t] and [z] environments, a total of eight significant differences. Whatever the environment, the vowel [ɑ] is always judged to be more nasal relative to all other vowels except [æ]. From a possible 36 differences among environments for any one vowel the following significant differences obtain: 12 for the vowel [i], 14 for the vowel [æ], 16 for the vowel [u], 18 for the vowel [ʊ], 19 for the vowel [ɛ], and 20 for the vowel [ʌ].

Since there are no significant changes in the rank order of vowels in the various types of environments, as shown in Table 8, and because the direction of differences from vowel to vowel for the two classifications of manner of production is the same (except for the vowel [æ] in voiced and voiceless

environments) an evaluation of the difference between voiced and voiceless and between plosive and fricative environments for all vowels combined seems justified, regardless of any interaction with vowels. The results of the *F* tests of the effects of voicing and of manner of production of consonant environments, mentioned earlier, are significant. Syllables with voiced environments are significantly more nasal than syllables with voiceless consonant environments. The means are 3.90 and 3.44, respectively. Syllables with fricative environments are significantly more nasal than syllables with plosive environments. These means are 3.83 and 3.52, respectively.

Although the interaction between voicing of environments and manner of production of environments is significant, there are no reversals of direction of difference between corresponding classifications of the two factors. Syllables with voiced environments were more nasal than syllables with voiceless environments both for plosive and for fricative environments. Syllables with fricative environments were more nasal than syllables with plosive environments both for voiced and for voiceless environments. The obtained means, in order from smallest to largest, are 3.20 for voiceless plosives, 3.68 for voiceless fricatives, 3.83 for voiced plosives, and 3.98 for voiced fricatives. A summary of *F* tests is given in Table 8. The only nonsignificant difference is between voiced fricatives and voiced plosives. Arranged from least to most nasality, the individual consonant-environment means averaged over vowels are as follows: no consonant, [z], [v], [d], [g], [f], [s], [t], and [k]. These results, with respect to order, are in exact agreement with the four means reported above for voiced and voiceless fricative and plosive environments. The critical difference necessary for significance at the 5% level is .47.[3]

Discussion

The nasal voices, as expected, were perceived as more nasal than the nonnasal voices. For the two groups, however, the trends of severity over vowels and over environments were essentially the same.

Results of this study indicate that severity of nasality, in general, increases progressively from the high vowels to the low vowels. Results of x-ray studies of velopharyngeal closure for normal speakers (*21, 22*) indicate that complete closure is characteristic of production of high vowels but not of low vowels. The increase in nasality from the high to the low vowels thus might be predicted for nonnasal voices. In view of the same trend for nasal voices, it seems reasonable that variations in degree of velopharyngeal closure accompanying variations in degree of nasality, with reference to vowels, are the same for both groups. The difference between the two groups with respect to vowels might thus be explained mainly in terms of degree of closure.

The vowel [æ] is largely responsible in the present study for any interactions among groups and vowels and evironments. The vowel [æ] is also responsible for the only reversal in direction of difference between syllables with voiced environments and syllables with

[3]Critical difference $= t_{.05}(2ms_{error}/n)^{1/2}$. See Table 1 for the error term employed.

voiceless environments. A possible explanation is that severity of nasality may be less closely related to degree of velopharyngeal closure on the vowel [æ] than it is on other vowels and that for this vowel some other factor (or factors) may be relatively more influential. Results of another study (*19*), concerned with cleft palate speakers, indicate no significant correlation between the mean nasality ratings of the vowel [æ] and adequacy of velopharyngeal closure as measured with a wet spirometer, a result which supports the hypothesis that degree of closure is not closely related to severity of perceived nasality on this vowel.

The various trends of severity of nasality are very similar for the two groups of speakers, but, even so, several specific differences are worth noting. The smallest differences between the two groups are on vowels with no-consonant environment, particularly the vowels [i], [æ], and [ʊ] on which there are essentially no differences. The greatest separations between the two groups on vowels with no-consonant environment are on the two vowels [ʌ] and [ɑ], both low vowels. It has been suggested (7) that as tongue height increases from [ɑ] and [æ] to [i] and [u], velar elevation also increases, so that closure is more precise for the high vowels than for the low vowels. In the present study the nasal speakers are relatively more nasal, in comparison with the nonnasal speakers, when closure is expected to be less precise. Also, the nonnasal group is more severely nasal, on the average, for isolated vowels than for CVC syllables. This is not true for the nasal group. It seems possible that the nonnasal speakers achieved more adequate velopharyngeal closure when producing CVC syllables because of the necessity for building up oral breath pressure for the production of accurate consonant sounds. Adequate velopharyngeal closure seems less likely on isolated vowels than on vowels preceded and followed by a consonant. The relatively wide separation between the two groups of speakers on CVC syllables suggests that the nasal group achieved less adequate closure for the consonants than did the nonnasal group. A subjective impression of the experimenters was that articulation of the consonants was not as precise for the nasal speakers as it was for the nonnasal speakers. A relatively important clinical implication would be that attention to precise production of consonants might be expected to reduce nasality.

As mentioned previously, nasality of vowels appears to vary with height of tongue position. According to Kenyon and Knott (*11*), the progression from high to mid to low tongue position, for the vowels used in the present study, is in the order following: [i], [u], [ʊ], [ɛ], [ʌ], [æ], [ɑ]. The obtained order of vowels ranked according to severity of nasality shows a relationship to this progression. Vowels, averaged over all environments, increase in nasality from high to mid to low tongue position. This would be expected in view of the previously mentioned assumption of relationship between height of tongue and velopharyngeal closure. The high vowels [u] and [ʊ] are always significantly less nasal than the low vowels [ɑ] and [æ], regardless of environment. The high vowel [i] is always significantly less nasal than the low vowel [æ] and is less nasal than the [ɑ], although the difference is statistically

significant for only the voiceless fricative environments. The vowel [i], however, is also significantly different from the vowel [u] in all but the voiced fricative environments, and ranks in the middle of the nasality continuum along with the mid vowels [ɛ] and [ʌ]. According to House and Stevens (*9*), when tongue height is held constant the front vowels require a slightly smaller area of nasal coupling to be judged nasal than do the back vowels. A variation in closure may thus account for the obtained significant difference between the high front vowel [i] and the high back vowel [u]. The low vowel [æ] has the highest nasality rating regardless of environment. The low vowel [ɑ] has the next to the highest nasality rating except in the no-consonant environment.

Severity of nasality on vowels in all environments combined appears to be related also to the front-back classification of vowels, although not as closely as to tongue height. According to Kenyon and Knott (11), the order of vowels, from front to back tongue position, is [i], [ɛ], [æ], [ʌ], [ɑ], [ʊ], [u]. The obtained order of vowels, averaged over all environments, corresponds relatively closely to this progression, with most severe nasality on the front vowels and least on the back vowels. The front vowels [i], [ɛ], and [æ] are always perceived as more nasal than the back vowels [u] and [ʊ]; the only consistently significant differences are between the front vowel [æ] and the back vowels [u] and [ʊ]. The back vowel [ɑ], however, which is always significantly more nasal than the other back vowels, regardless of environment, is perceived as more nasal than the front vowels [i] and [ɛ], with one exception for [i] in the no-consonant environment. This increase of severity of nasality from back to front tongue position agrees with the House and Stevens (*9*) findings relative to this classification of vowels.

The obtained order of vowels in combined environments with respect to severity of nasality is exactly opposite that order found for cleft palate speakers. Spriestersbach and Powers (*19*) found that mean scale values of nasality increased from smallest to largest for isolated vowels in the following order: [ɑ], [ʌ], [æ], [ɛ], [u], [i]. Buck (*2*) and Morley (*14*) also indicate that perceived nasality increases in severity for cleft palate speakers from the low to the high vowels, with the vowel [ɑ] the least nasal and the vowels [i] and [u] the most nasal. This reversal in order of severity of nasality for vowels produced by cleft palate speakers and those produced by the speakers in the present study appears related to amount of velopharyngeal closure. Where adequate closure is a problem, as is likely with cleft palate speakers, it would be expected that the high vowels, which require the most complete closure for nonnasal production, would be perceived as more severely nasal than the low vowels, which typically require less complete closure. For functionally nasal and for normal speakers, however, x-ray data indicate that velopharyngeal closure is generally more likely to be complete for the high vowels and not to be complete for the low vowels. On this basis, it could be hypothesized, then, that the low vowels would be perceived more severely nasal than the high vowels for these two groups of speakers.

Because of the relationship between degree of nasality and height of the tongue, and in view of the observations of Joos (*10*) and Peterson (*15*), linking the conventional physiological classification of vowels to acoustical phenomena, a consideration of some of the acoustical characteristics of vowels as they vary with height of the tongue seems relevant. Studies of normal voices (*1, 4, 16, 20*) provide evidence that high vowels have higher fundamental frequencies than low vowels with the mid vowels falling between the two extremes. Various investigators (*1, 4, 8*) have found that generally the high and mid vowels have shorter durations than do the low vowels. Also known (*1, 6, 18*) is the fact that high and mid vowels have less average intensity and less average peak power than do low vowels.

Results of this study provide evidence that, in general, with changes of vowel quality and with consonant environment held constant, perceived nasality on vowels decreases as height of tongue position increases. A reasonable inference, then, is that the degree of nasality is influenced by the acoustical characteristics which vary with the height of tongue position. Although a causal relationship is not thus established, nasality apparently does increase with (a) lower fundamental frequency, (b) longer duration, (c) higher average intensity, and (d) higher average peak power.

Acoustical characteristics of vowels are known to vary systematically also with type of consonant environment, most particularly when these environments are categorized with reference to voicing, that is, voiced or unvoiced, and with reference to manner of production, that is, plosive or fricative (*8*). The effects of voicing are greater than those of manner of production. Vowels in voiced environments are longer in duration, lower in fundamental frequency, and greater in relative power than are vowels in voiceless consonant environments. Vowels in fricative environments are longer in duration, lower in fundamental frequency, and greater in relative power than are vowels in plosive environments.

Nasality is less severe for syllables with voiceless environment than for syllables with voiced environment. It is less severe for syllables with plosive environment than for syllables with fricative environment. When comparisons are made among syllables in all four types of environment, the order of severity of nasality from most to least is voiced fricatives, voiced plosives, voiceless fricatives, and voiceless plosives. Voicing thus appears to have a somewhat greater influence on nasality than does manner of production.

Differential effects upon physical characteristics of vowels, as pointed out above, are known to accompany, in a lawful manner, changes in vowel quality and certain changes in the consonant environment of the vowel. Variations in severity of nasality, according to the results of the present study, follow the same pattern. Nasality thus apparently increases with lower fundamental frequency, longer duration, and higher intensity. This is true both when the changes in acoustical characteristics are related to changes in vowel quality and when they are related to changes in the consonant environment of the vowel. A causal relationship thus seems likely. The most readily apparent explanation is the possibility that the

nasality, or its acoustical correlates, simply becomes more conspicuous to the listener because of lower fundamental frequency, longer duration, and/or higher intensity.

The results of the present study parallel quite closely those of a very similarly designed investigation of harsh voice quality (*17*). Harshness increases, as does nasality, with lower fundamental frequency, longer duration, and higher relative power. These deviations of voice quality, nasality and harshness, are assumed, however, to be associated with different etiological factors. Fairbanks (*5*) states that nasality is a resonance problem and that the distinguishing feature of harshness is irregular, aperiodic noise in the vocal-fold spectrum. It seems possible that any deviant voice quality becomes more conspicuous to the listener with the above-mentioned changes in physical characteristics of vowels.

In summary, it is apparent that perceived nasality varies with a number of parameters. Examination of data on velopharyngeal closure related to these parameters suggests that relatively inadequate closure may be the most important cause of functional nasality. There is some indication that lack of precision in articulation of consonants may be associated with this voice quality. A consideration of the obtained results along with data from other studies leads also to the conclusion that degree of perceived nasality varies with fundamental frequency, duration, and intensity of vowels.

Summary

The purpose was to study influences of vowel quality and consonant environments on nasality. Vowels were [i], [ɛ], [æ], [ʌ], [ɑ], [ʊ], and [u]. Consonants were voiced plosives [d] and [g], voiceless plosives [t] and [k], voiced fricatives [v] and [z], and voiceless fricatives [f] and [s]. Stimulus materials were the vowels in isolation and in CVC syllables with the same consonant preceding and following each vowel. These were recorded by each of 20 voices, 10 nasal and 10 nonnasal. Median scale values of nasality on a seven-point scale were derived from responses of 35 listeners.

The trends of severity of nasality were, in general, essentially parallel for the two groups but were somewhat more widely separated on CVC syllables than on isolated vowels. Nasality of vowels for environments combined varies (a) with height of tongue position, the higher vowels less nasal than lower, and (b) with the front-back classifications, the back vowels less nasal than front. Syllables are less nasal (a) with voiceless environments than with voiced environments and (b) with plosive environments than with fricative environments. Nasality is least severe for voiceless plosive environments, more severe for voiceless fricative and voiced plosive environments, and most severe for voiced fricative environments.

Summario in Interlingua

Le proposito esseva studiar influentias de vocal qualitate e consonante ambientes sur nasalitate. Vocals esseva [i], [ɛ], [æ], [ʌ], [ɑ], [ʊ], e [u]. Consonantes esseva plosives con voce [d] e [g], plosives sin voce [t] e [k], fricatives con voce [v] e [z], e fricatives sin voce [f] e [s]. Stimulo materials

esseva le vocals in isolation e in consonante-vocal-consonante syllabas con le mesme consonante precedente a sequente cata vocal. Istes esseva recordate per cata de vinti voces, dece nasal e dece nonnasal. Median scalia valutas sur un septepuncta scalia esseva derivate de responsas de trenta-cinque ascoltators.

Le tendentias de severitate de nasalitate esseva, in general, essentialmente parallelo pro le duo gruppos sed esseva aliquanto plus latamente separate sur consonante-vocal-consonante syllabas que sur vocals in isolation. Nasalitate de vocals pro ambientes combinate varias (a) con altitude de position de lingua, le supere vocals minus nasal que inferior, e (b) con le fronte-post classification, le post vocals minus nasal que fronte. Syllabas esse minus nasal (a) con ambientes sin voce que con ambientes con voce e (b) con ambientes de plosives que con ambientes de fricatives. Nasalitate es minime sever pro ambientes de plosives sin voce, plus sever pro ambientes de fricatives sin voce e plosives con voce, e le plus sever pro ambientes de fricatives con voce.

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► RESEARCH NEWS NOTE

Consistency Effect in Stuttering Expectancy

► The present investigation was concerned with the consistency effect in stuttering expectancy, a subject not covered in the literature, and was part of a larger study of adaptation and recovery in the stuttering expectancy paradigm (*J. Speech Hearing Res.*, 4, 1961, 91-99). The question asked was whether or not a consistency effect could be demonstrated in the expectancy paradigm. An experimental group of 16 stutterers read a passage silently five times on each of four consecutive days and underlined words on which they expected they would stutter if they were reading the material orally to the group. A control group of 16 stutterers read the passage aloud five times on each of four consecutive days. Both groups then read the passage aloud five successive times.

Mean consistency indexes, computed by the formula used by Johnson and Inness (*J. Speech Dis.*, 4, 1939, 79-86), were found within the expectancy paradigm of an order of magnitude similar to those reported in oral reading studies. Data on mean consistency indexes and standard deviations together with the *t* values for both groups are summarized in Tables 1 and 2. None of the differences between the performances of the two groups with regard to the consistency effect were significant at the 5% level.

This experiment provides evidence that a consistency effect can be demonstrated in the expectancy paradigm: the loci of stuttering expectancy remained relatively constant from reading to reading over the course of four days; more than half of the words expected to be stuttered on a given reading were expected to be stuttered on a previous reading. Thus, expectancy of stuttering ap-

TABLE 1. Mean consistency indexes and standard deviations for the experimental group and the control group for five readings on Day 1, together with *t* values for the differences between the means of the two groups. None of the differences were significant at the 5% level.

Readings Compared	*Experimental*		*Control*		*t**
	Mean	*SD*	*Mean*	*SD*	
2 and 1	55.81	25.46	51.12	21.81	.14
3 and 2	58.81	28.50	54.93	25.23	.10
4 and 3	57.56	32.59	47.56	24.54	.24
5 and 4	55.56	38.37	49.68	33.19	.12
5 and 1	52.81	32.04	50.06	30.53	.06

* $t_{.05}$ $(df = 30) = 2.04$.

TABLE 2. Selected mean consistency indexes and standard deviations for five readings (R1, ..., R5) for the experimental group and the control group on four days (D1, ..., D4) together with *t* values for the differences between the means of the two groups. None of the differences were significant at the 5% level.

Readings Compared	*Experimental*		*Control*		*t**
	Mean	*SD*	*Mean*	*SD*	
R1, D2 and R5, D1	48.68	30.64	40.75	25.49	.77
R1, D3 and R1, D2	56.31	16.15	42.43	27.54	1.68
R1, D4 and R1, D3	65.31	18.17	50.87	28.20	1.67
R5, D4 and R1, D4	60.50	28.60	52.31	27.83	.79
R6, D4 and R5, D4	27.68	35.31	45.56	20.84	1.69

* $t_{.05}$ $(df = 30) = 2.04$.

pears to behave in a lawful manner or with a consistency of predicability to stimuli or cues as does the occurrence of actual stuttering. This finding is consistent with Johnson's (*Stuttering in Children and Adults*, 1955, p. 16) interpretation of the consistency effect in stuttering, namely, that the consistency effect implies that stuttering 'behaves like a response made to identifiable stimuli or cues with a very considerable degree of consistency or predicability.'

The present data appear to support Johnson's hypothesis that stutterers have learned or become conditioned to react with fear, dread, or anxiety to certain words (or the linguistic characteristics associated with them). Hence, words may become associated with previous feelings of anxiety and may function, as Johnson suggests, as 'danger signals' or 'noxious stimuli' on the nonovert as well as on the overt level of stuttering.

Since the experimental group was consistent in predicting loci of stuttering on silent inspections of the material, it is difficult to explain why the subjects were not very accurate in their predictions of loci of stuttering in reading aloud. Such a disparity between performances raises anew the question of the dynamics underlying the expectancy paradigm.

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► RESEARCH NEWS NOTE

Identification and Training of Institutionalized and Retarded Deaf Patient

► The purposes of this project are: (a) to survey the deaf population in Michigan's State Home and Training Schools for the mentally retarded to ascertain their characteristics and vocational rehabilitation needs; (b) to identify and assess the medical, psychological, and social characteristics of the retarded deaf patient in these schools; (c) to make proper diagnosis a substantive factor in the survey leading to the differentiation between the mentally retarded deaf, the deaf retarded, and the improperly committed deaf; (d) to plan a training program which will be aimed at meeting the vocational rehabilitation needs identified from the survey; and (e) to demonstrate the feasibility of a statewide vocational rehabilitation program for these patients.

The justification of this study was based on a 1960 survey conducted in all of Michigan's State Home and Training Schools, in which 585 patients were tentatively identified as hard-of-hearing or deaf. The validity of this figure is seriously in doubt since no means are presently available to indicate the extent to which audiological, medical, or psychological factors were used in making the identification.

The project will be conducted at the Coldwater and Lapeer State Home and Training Schools under the joint direction of the Michigan Department of Mental Health and the Lapeer State Home and Training School. All of the relevant facilities of these three units will be available to the project staff. These include: (a) a professional staff of researchers from many disciplinary backgrounds which relate to the present project, e.g., psychiatry, clinical psychology, mathematical statistics, nursing, special education, social work, and medicine; (b) consultative services from specialists in the above and additional fields including audiology and vocational rehabilitation (these specialists are from various departments of state government, universities, and hospitals within the state); (c) two dynamically oriented home and training schools; (d) modern, high speed data processing equipment.

This investigation will take three years to complete and is supported by a research contract with the Office of Vocational Rehabilitation, Department of Health, Education and Welfare.

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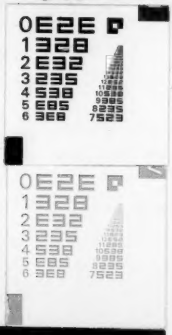
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